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FINAL YEAR PROJECT

TITLE: AN OVERVIEW OF GEOTHERMAL ENERGY IN KENYA.

PROJECT NO. 1

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DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

DEDICATION

To my father John and my mother Patricia for humbly nurturing me, their kindness, understanding, love and guidance and above all for being my parents. Without you I Would not be what I am today.

Thank you and may God's blessings be upon you always.

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I wish to express my sincere and deep gratitude to all of you who in many ways have contributed to the fulfillment of this report. I am especially grateful to:

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Finally but most important my parents, brothers and sisters for their love and endless support, for always being there for me and giving me strength to continue.

THANK YOU ALL!!!!

ABSTRACT

Geothermal power is a form of energy stored in rocks and fluids within the earths crust. This form of energy is renewable. If well tapped, it can be used in production of electricity, heating in green houses and a source of tourist attraction. Due to unreliable rain patterns, and the fact that Kenya relies highly on hydropower, the electricity supply has become unreliable especially during the dry season. An example of this scenario was experienced in the year 2000 which was a great drawback to the country's economic development. Kenya is endowed with vast geothermal resources, mainly located in the Rift valley. Electricity demand in the country has risen over the years, causing great pressure on the conventional sources of energy like hydropower, which is normally affected by the weather changes. This is unlike geothermal resources which are yet to be substantially tapped hence the need to develop geothermal energy.

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ACRONYMS

IPP	Independent Power Producer
KENGEN	Kenya Energy Generating Company
MW	Mega Watt
KPLC	Kenya Power and Lighting Company
ERB	Energy Regulatory Board
KVA	Kilo Volt Ampere
KV	Kilo Volt
MV	Mega Volt
MVA	Mega Volt Ampere
NREL	National Renewable Energy Laboratory
GDC	Geothermal Development Company
CO_2	Carbon dioxide
Lb/KWh	Pound per Kilo Watt hour
dB	Deci bel
H_2S	Hydrogen Sulphide
AT	Ampere Turn
Ohm-m	Ohm meter

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CHAPTER ONE: INTRODUCTION

1.1 Overview

Geothermal power is the thermal energy stored in rocks and fluids within the earth. It is derived from the heat of the earth's core. It is clean, abundant and reliable. If properly developed it can offer a renewable and sustainable energy source. Geothermal energy is applied in electricity generation, direct use of heat and ground source heat pumps. Direct heat include heating green houses and drying foods while ground source heat pumps are used to heat and cool buildings using surface soils as heat reservoir.

1.2 Objective of the project

This project was initiated by Mr.N.S Walkade of the University of Nairobi in December 2008. The main aim of this project was to carry out in depth research in geothermal energy in Kenya.

The specific instruction was to study the status and potential capacity for Kenyan grid system.

1.3 Outline

The report is organized into six chapters as follows:

Chapter two describes the origin, history and exploration of Geothermal energy and its resources. It also gives its Location, prospects in Rift valley and other Kenyan sources of energy.

Chapter three describes the resource identification, Olkaria Geothermal system and its exploration. It also explores its generation, transmission and the geothermal power technologies

Chapter four deals with the cost of generation and the current status of geothermal development

Chapter five elaborates the future development status

Chapter six describes the uses of geothermal energy, the factors affecting it and the ways of improving them.

Chapter seven gives the conclusions and recommendations

CHAPTER TWO: BACKGROUND.

2.1: Origin of geothermal resources

Geothermal energy comes from earth's internal heat whose temperature increases with depth. The temperature at the center reaches more than 4200 degrees Celsius due to a relic of the planet's formation and continuing decay of radioactive isotopes. The heat flows from its interior towards the surface. Due to plate tectonics, Earth's crust broke into 12 plates that move apart or push together .During their collision, they cause ocean trenches and earthquakes. At great depths, temperatures become very high to melt rock, forming magma. Since magma is less dense than the surrounding rock, it moves up towards the earth's crust and carries heat from below.

Sometimes magma rises to the surface through fractured surface as lava. Most magma remains below earth's crust and heats the surrounding rocks and subterranean water. Some of this water becomes all the way up to the surface through faults and cracks in the earth as **hot springs** or **geysers**. When this rising hot water and steam is trapped in permeable rocks under a layer of impermeable rocks, it is called **Geothermal reservoir**. These reservoirs are sources of geothermal energy that can potentially be tapped for electricity generation or direct use. The production well withdraws heated geothermal fluid and the injection well returns cooled fluid to the reservoir.

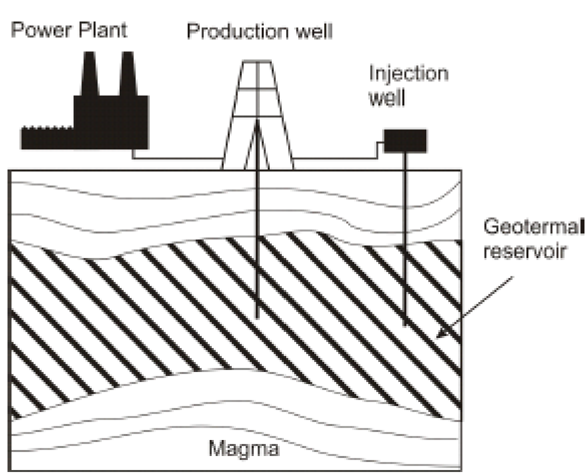

Figure 2.1: Schematic of geothermal power plant production and injection wells

2.2: History of geothermal energy

General

Geothermal Energy was first harnessed in Italy in 1904 by prince piero but its growth was slow because of cheap competition sources of Electric power. The first geothermal power plant in the United States was operated in 1960 at the Geysers in Sonoma County, California.

Kenya

Geothermal production began in Kenya at Olkaria when the first 15 MWe generating unit was commissioned in June 1981 and the second 15 MWe was in November 1982. The third unit was commissioned in March 1985 raising the total installed capacity at Olkaria to 45 MWe. The other geothermal generation capacities are Olkaria II, which is currently producing 70 MWe, owned by KenGen and Olkaria III which is owned by an IPP (ORMAT) and is currently producing 12 MWe and plans are in progress and at and to increase its production to 48 MW by end of 2005.

2.3: Exploration

Exploration first started by drilling two wells in 1956 in Olkaria I and was followed by increased interest in the 1970s. Initial production started in 1981 when the first plant of 15MW was commissioned in Olkaria I currently 45MWe is generated by Olkaria I geothermal power station; 70 MWe is produced from Olkaria II (both operated by KenGen) and an IPP is producing12Mwe at Olkaria III. KenGen and the IPP produce a total of 129 MWe of geothermal energy and this is expected to increase to 576MWe within the next 20 years. Drilling of three exploratory wells at Olkaria IV was done between 1998 and 1999.Thereafter six appraisal wells were drilled at the prospect between July 2007 and June 2008.Development is currently going on for the construction of a 140MWe power plant. Exploratory drilling was carried out at Eburru between 1988 and 1990.A potential of 20MWe was identified. Over the years, surface exploration has been going on at various geothermal prospects

2.4: Location

Kenya is endowed with geothermal resources mainly located in the Rift Valley. Electricity demand in Kenya has continued to grow steadily over the years and has caused great pressure on the conventional sources of energy like hydropower, which is normally affected by weather changes. It is estimated conservatively that the Kenya Rift has a potential of greater than 2000 MWe of Geothermal Power. A total of twenty sites have been earmarked for further investigation.

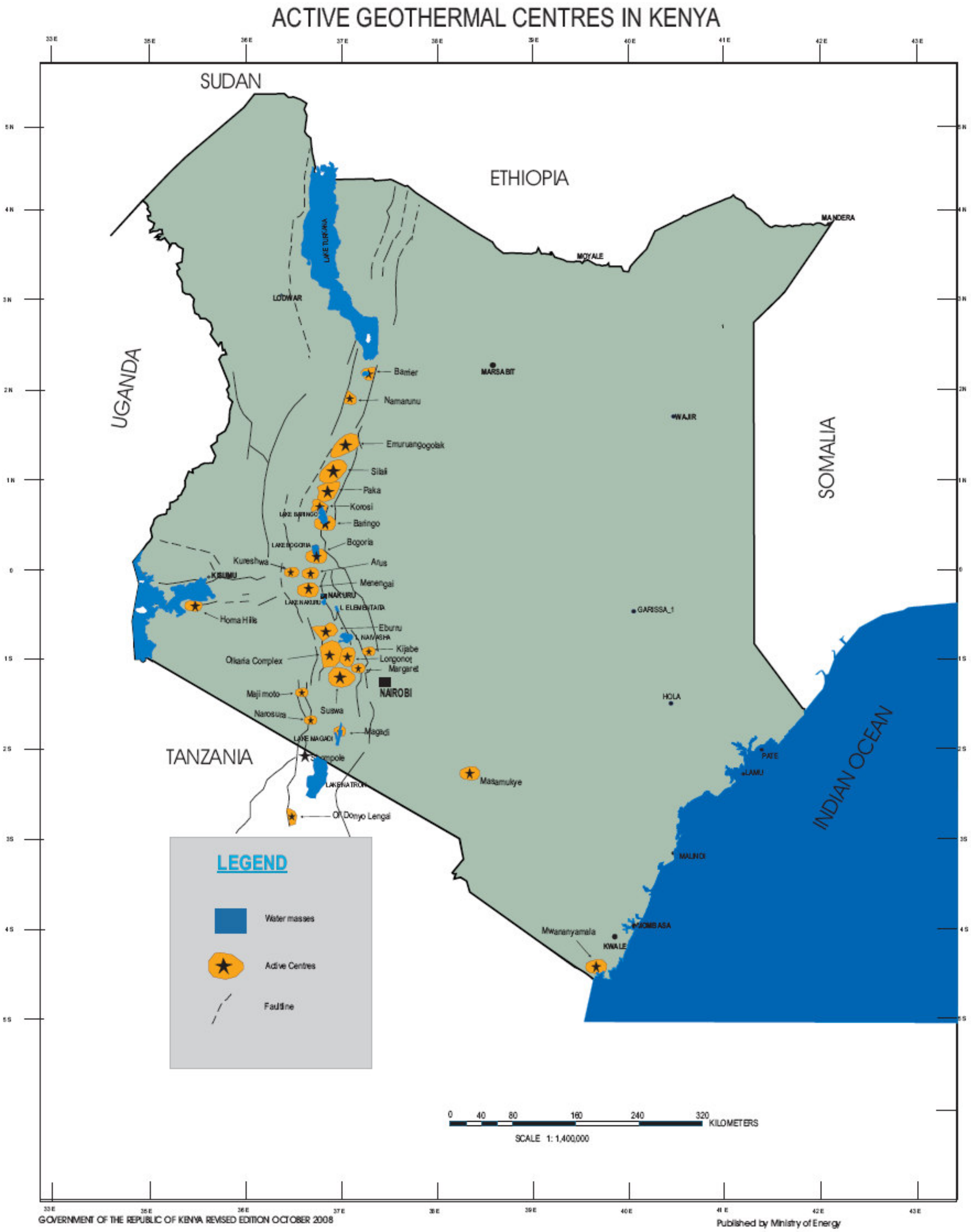

Figure 2.2: A map showing the Active geothermal centers in Kenya

2.5: Geothermal Prospects in North Rift

The north rift geothermal systems extend from immediately north of Menengai to the central Island in L.Turkana.They comprise of Bogoria,Baringo,Korosi,Silali,Emuruangogolak,Namarunu,Barrier Volcano and the central island geothermal prospects. They are in different stages of exploration.Bogoria; Baringo, Korosi and paka have been assessed in detail and wells for drilling exploration sited. Development of two 70MWe geothermal power plant each from the best north rift prospects has been projected for commissioning by 2018.

Active geothermal centre in Kenya.

The identified geothermal potential in the country is estimated at 7,000MW.However, only 130MW of this potential has so far been harnessed. The large untapped potential makes Geothermal the most promising indigenous energy resource for development of electricity in Kenya

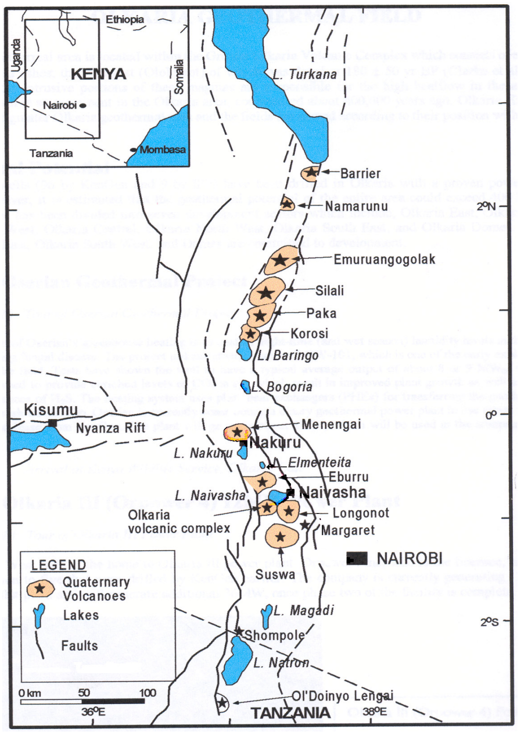

Figure 2.3: A map of geothermal prospects in Rift valley.

2.6: Kenya's source of Energy

Kenya relies on three major sources of energy. These are **Biomass** (**68%**)**, Petroleum** (**22%**) and **Electricity** (**9%**) of the total energy used**.** Kenya's geothermal potential exceeds 2000 MW and its economic hydro sites have largely been developed**.** Unfortunately, Kenya has no oil or coal.

According to Kenya's source of energy, the Electricity sub-sector consists of Hydropower, Thermal power and Geothermal power where the hydropower (62%) dominates this sector, followed by thermal power (26%) and geothermal power (12%). Other forms of renewable energy include wind, solar, biogas and mini hydro whose total outputs contribute to 1% of the total energy.

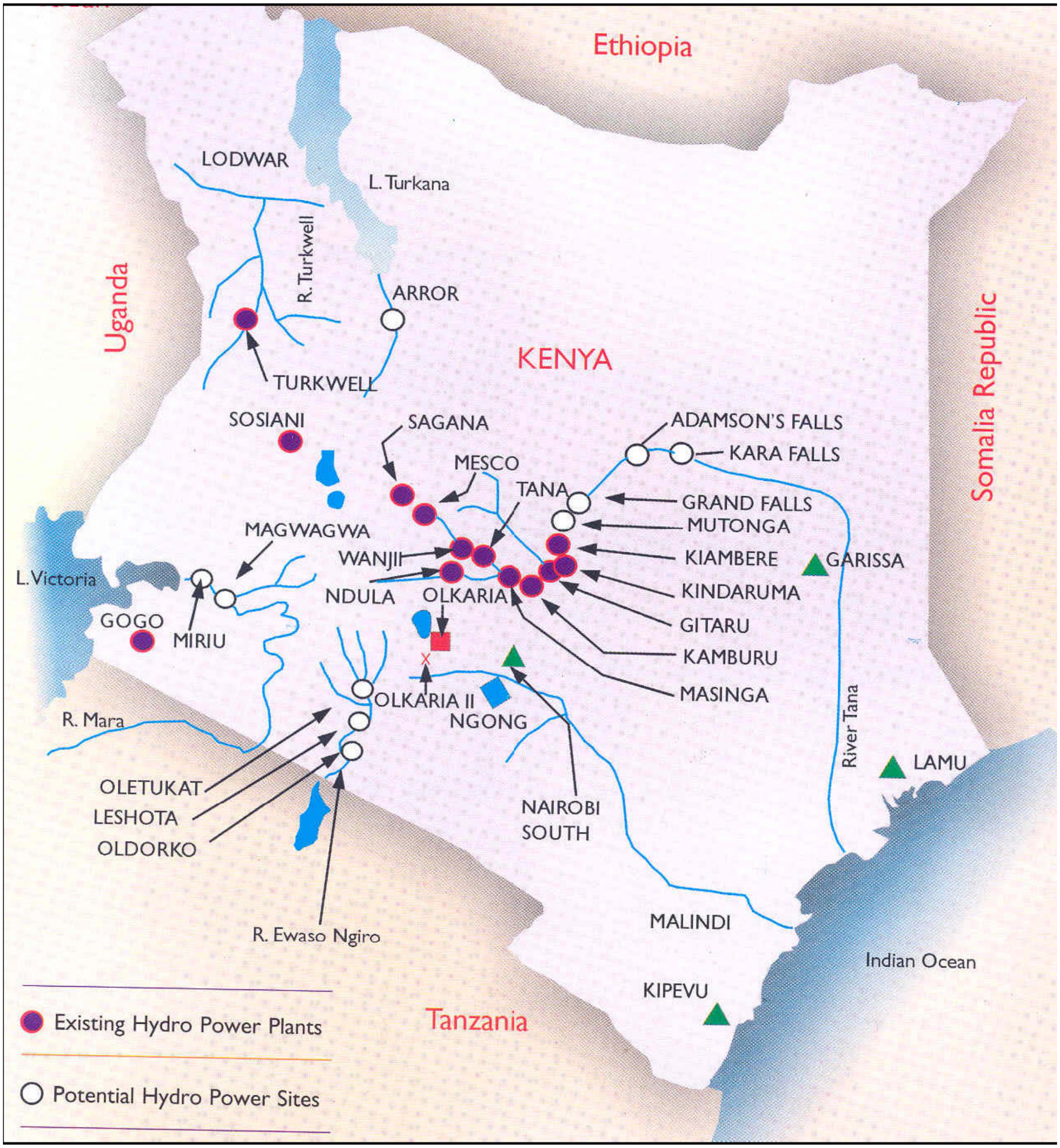

Figure 2.4: A map showing existing and potential power plants of KenGen.

Preference to Geothermal energy

Due to unreliable rain patterns, and the fact that Kenya relies highly on hydropower, the electricity supply has become unreliable especially during the dry season. An example of this scenario was experienced in the year 2000 which was a great drawback to the country's economic development. Kenya is endowed with vast geothermal resources, mainly located in the Rift valley. Electricity demand in the country has risen over the years, causing great pressure on the conventional sources of energy like hydropower, which is normally affected by the weather changes. This is unlike geothermal resources which are yet to be substantially tapped.

Development of geothermal energy which is indigenous, low cost environmentally benign and reliable seems to be the long-lasting solution to this problem. The least cost power development plan for the year 2004 (KPLC,2004) has considered geothermal energy as a least cost source of electric power in Kenya to replace the medium diesel plants which were in the earlier plans.

The government of Kenya has demonstrated a great commitment to the exploration and exploitation of geothermal energy. About 8 million US dollars will be set aside, every year for the next five years, for geothermal exploration in the Rift valley. More funds are being sought from development partners for exploitation of the already proven geothermal resources i.e. Olkaria IV, Eburru, Suswa, Longonot and Menengai.

Kenya is endowed with a rich geothermal resource, mainly located in the Rift valley. Electricity demand in the country has risen over the years, causing great pressure on the conventional sources of energy like hydropower, which is normally affected by weather changes. This is unlike geothermal resources which are yet to be substantially tapped. The identified geothermal potential in the country is estimated at 7,000 MW. However, only 130MW of this potential has been harnessed. The large untapped potential makes geothermal the most promising indigenous energy resource for development of electricity in Kenya.

2.7: Electricity contribution by different sources.

The installed electricity capacity in Kenya currently stands at 1,232.6 MW. This includes a firm 20 MW import from Uganda, and 74 MW from Kipevu II diesel plant, which came into commercial operation in August 2001, 70MW from Olkaria II which was fully commissioned in November 2003.

Table 2.1 Electricity contributions by different energy sources

Source	Capacity in MW	Percentage (%) of total capacity
Hydro (Including Imports)	**697.2**	**57.34**
Geothermal	**128**	**10.53**
Oil Thermal Generation	133.5	10.98
IPP’s (Thermal)	174.0	14.31
Gas Turbine	73.5	6.05
Wind	0.4	0.033
Isolated Diesel Plants	9.2	0.76
Total	1215.8	100

Table 2.2: Geothermal sites with exploration status.

Prospect	Reconnaissance Survey	Surface exploration	Drilling
Olkaria I	Completed	Completed	Done
Olkaria II	Completed	Completed	Done
Olkaria III	Completed	Completed	Done
Olkaria IV	Completed	Completed	Ongoing
Eburru	Completed	Completed	Done
Longonot	Completed	Completed	Not done
Suswa	Completed	Completed	Not done
Menengai	Completed	Completed	Not done
Badlands	Completed	Partial	Not done
L.Magadi	Completed	Not done	Not done
Arus	Completed	Done	Not done
L.Bogoria	Completed	Done	Not done
Baringo	Completed	Done	Not done
Korosi	Completed	Done	Not done
Paka	Completed	Done	Not done
Silali	Completed	Not done	Not done
Emuruangogolak	Completed	Not done	Not done
Namarunu	Completed	Not done	Not done
Barrier Volcano	Completed	Not done	Not done
Central Island,L.Turkana	Completed	Not done	Not done
Homa Hills	Not done	Not done	Not done
Mwananyamala	Not done	Not done	Not done

CHAPTER THREE: EXPLORATION AND CONVERSION TO ELECTRICITY

Electrical energy production, exploration and conversion in Kenya is carried out by various bodies.

Power industry players:

The following bodies help in the power production in Kenya

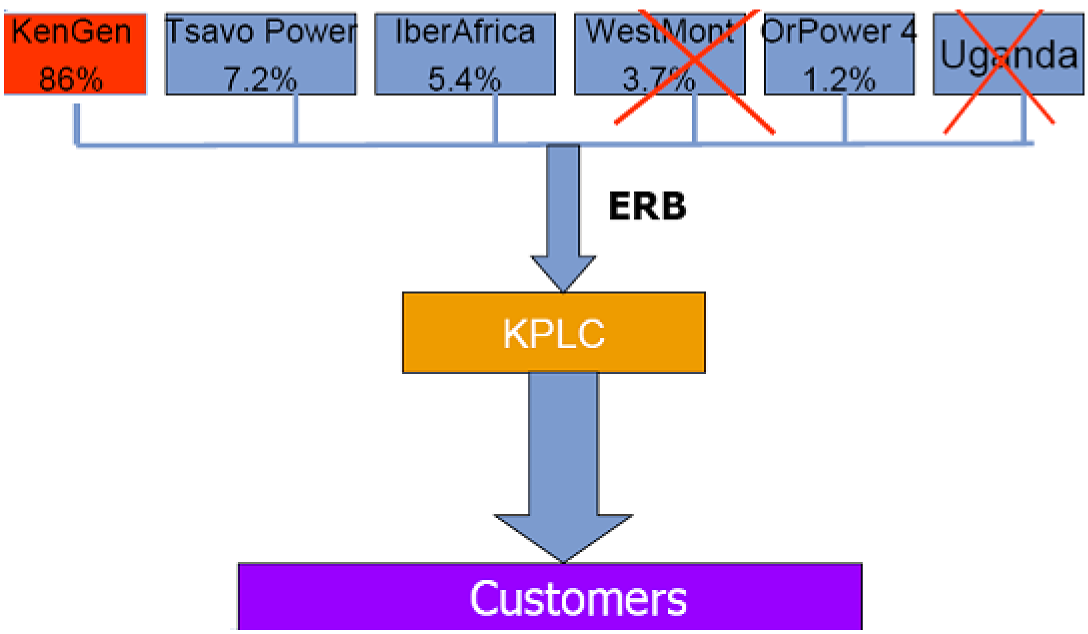

Figure 3.1 A chart representing power industry players

For geothermal exploration to be successful, various procedures have to be followed in order to identify the resource and exploit it.

3.1 Resource Identification

Geological, **hydrogeological, geophysical** and **geochemical** techniques are used to identify and quantify geothermal resources. Geological and hydro geological studies involve mapping any hot springs or other surface thermal features and the identification of favorable geological structures. These studies are used to recommend where production wells can be drilled with the highest probability of tapping into the geothermal resource. Geophysical surveys are implemented to figure the shape, size, depth and other important characteristics of the deep geological structures by using the following parameter: temperature(thermal survey),electrical conductivity(electrical and electromagnetic methods),propagation velocity of elastic waves (seismic survey),density (gravity survey),and magnetic susceptibility(magnetic survey).Geochemical survey(including isotope geochemistry) are a useful means of determining whether the geothermal system is water or vapor-dominated, of estimating the minimum temperature expected at depth, of estimating the homogeneity of the water supply and, of determining the source of recharge water.

Before geothermal exploration and exploitation takes place, the following steps have to be followed

1. Identification of geothermal phenomena.
2. Ascertaining that a useful geothermal production field exists.
3. Estimation of the size of the resource.
4. Classification of the geothermal field.
5. Location of productive zones.
6. Determination of the heat content of the fluids that will be discharged by the wells in the geothermal field.
7. Compilation of a body of data against which the results of future monitoring can be viewed.
8. Assessment of the pre-exploitation values of environmentally sensitive parameters.

(9) Determination of any characteristics that might cause problems during field development.

3.2 The olkaria geothermal system.

Location

The Olkaria geothermal system is located on the floor of the East Africa Rift valley in Kenya about 120 km North West of Nairobi. The resource is associated with the Olkaria volcanic complex which consists of a series of lava domes and ashes. The geothermal reservoir is considered to be bound by arcuate faults forming a ring or caldera structure. A magmatic heat source is represented by intrusions at deep levels inside the ring structure. Faults and fractures are prominent in the area with a general trend of N-S and E-W but there also some inferred faults striking NW-SE.

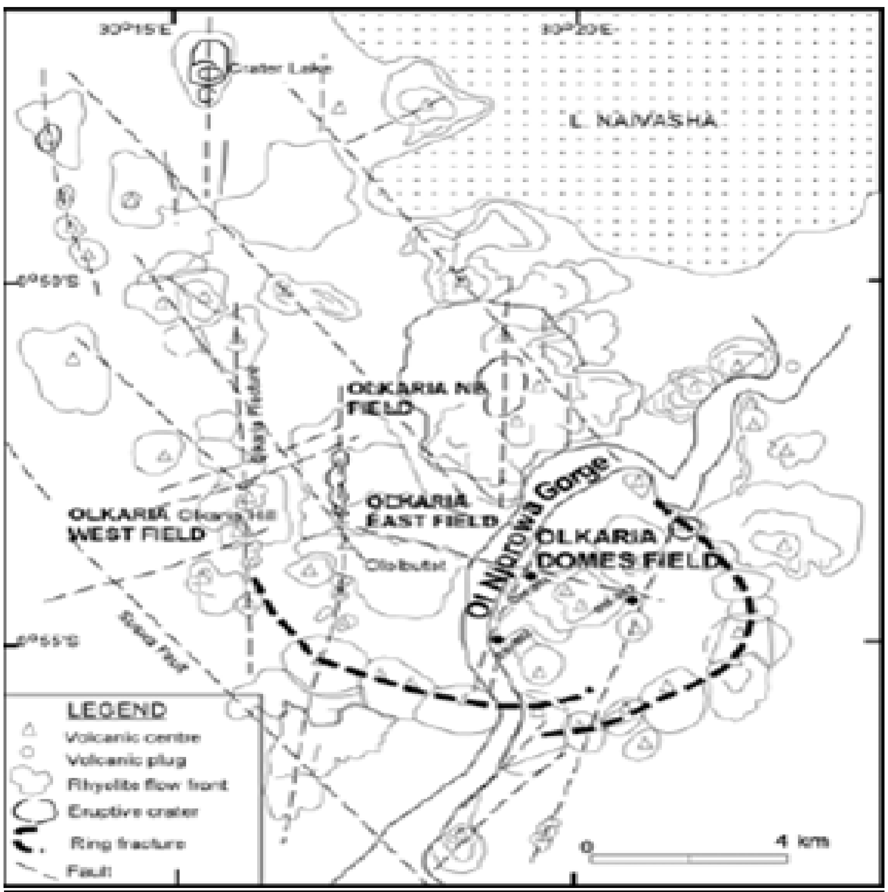

Figure 3.2: A volcano-tectonic map of greater Olkaria Geothermal complex

The Olkaria geothermal field

The Olkaria geothermal field covers an area of approximately 70 km^2. A total of 110 wells have so far been drilled out of which 50 are production wells, 24 for Olkaria I, and 22 for Olkaria II, 6 re-injection wells and four production wells in Olkaria III. The main production zones are generally between 750-900m being steam dominated and from 1100 metres to 1300 metres which is richer in water though steam can be intercepted down to the full depth of the well. Currently there is steam capable of generating an additional 25 MWe in Olkaria I and 28 MWe in Olkaria II.

3.3 Exploration and extraction

Drilling

Once potential geothermal resources have been identified, exploratory drilling is carried out to further quantify the resource. This drilling is quite expensive as compared to conventional petroleum drilling due to high temperature and corrosive nature of geothermal fluids as well as the hard and abrasive nature of the reservoir rocks found in geothermal environment.

Wells are drilled vertically or at an angle. They are drilled in a series of stages with each stage having a smaller diameter than the previous stage, and each being secured by steel casing, which are cemented in place before drilling the subsequent stage. The final production sections of the well use an uncemented perforated liner, allowing the geothermal fluid to pass into pipe. The objectives of this phase are to prove the existence of an exploitable resource and to delineate the extent and the characteristics of the resource. An exploratory drilling program includes shallow temperature gradient wells and production-sized exploration wells. Temperature-gradient wells are often drilled from 2 to 200 meters in depth with diameter of 50 to 150mm. slim-hole exploration wells are usually drilled from 200 to 300 meters in depth with bottomed hole diameters of 100 to 220 mm. The size and objective of development will determine the number and type of wells to be included in exploratory drilling programs.

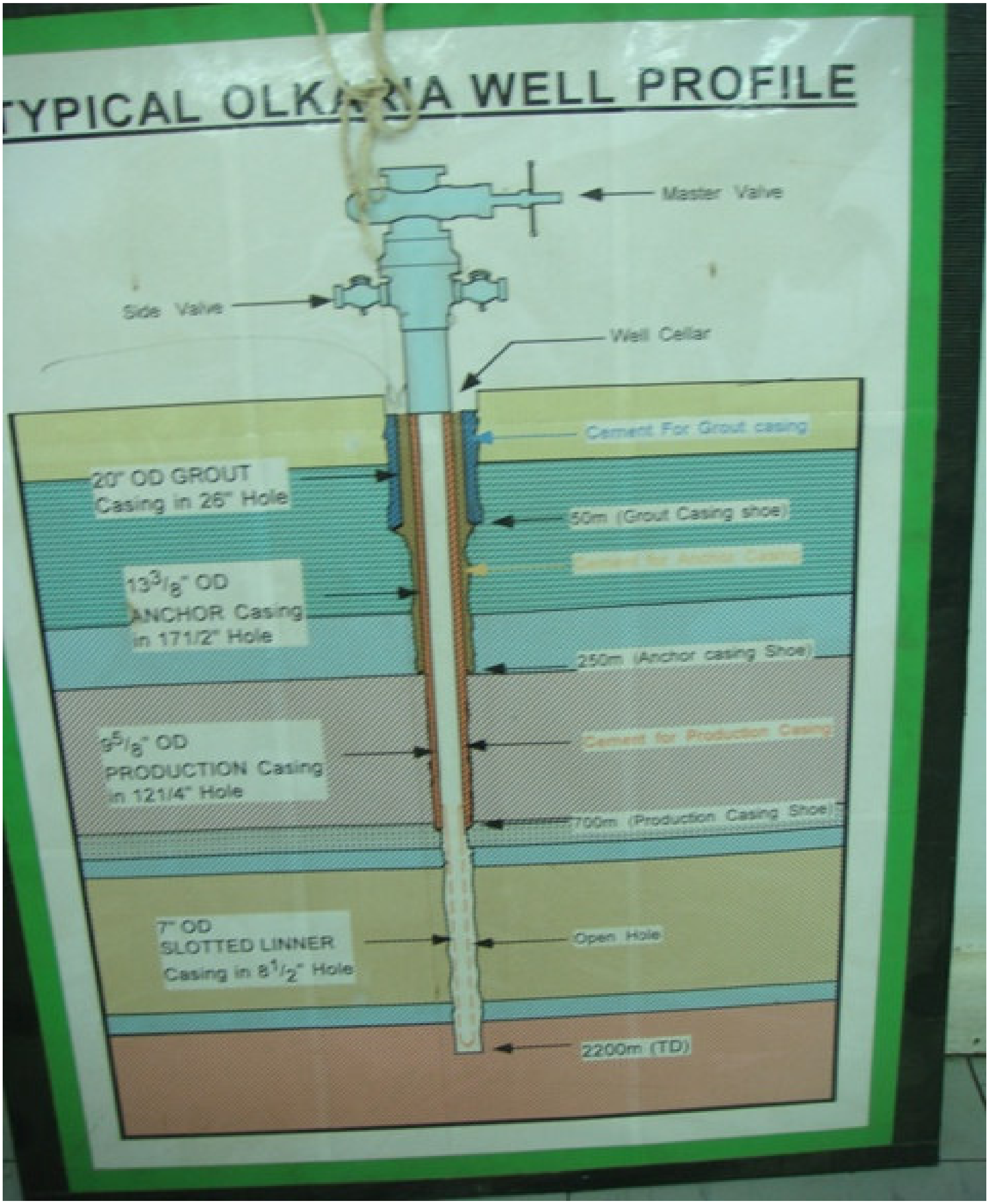

Figure 3.3: A typical Olkaria Well Profile

3.4 Steam supply system

The steam/water mixture from the geothermal well is led into a wellhead cyclone separator where the two are separated. On average the mixture is composed of 75% steam and 25% water. steam from a set of wells is collected and transmitted through a single pipeline(one for each turbine) to the turbine through a moisture separator(a secondary separator).The line pressure is regulated automatically by pneumatically operated pressure relief valves. Dry saturated steam at 0.5 bar abs. and 151.9 º C enters the turbine through two pipes from the moisture separator.

The hot water (at about 70 to 80°C) is discharged into an infiltration pond through a flow measuring v-notch installed at the outlet of the well-head silencer. This water is highly mineralized and is not fit for human consumption unless treated.

The three turbines are driven by steam from twenty one wells whose average steam and water flow, well head pressure and depths are summarized as follows.

Table 3.1: Olkaria East field wells characteristics

WELL	STEAM FLOW (t/h)	WATER FLOW (t/h)	OPERATING PRESS.(bar abs)	MAX. RECORDED SHUT IN PRESS (bar abs)	MAX. RECORDED TEMP(°)	DRILLED DEPTH (m)
Ow-2	21	6	5.8	35.3	282	1360
Ow-5	26	1	5.2	8.4	264	910
Ow-6	14	2	5.8	38	296	1885
Ow-7	10	3	7.7	38	254	1308
Ow-8	26	_	6.6		266	1600
Ow-10	19	2	5.0	47.6	274	1183
Ow-11	16	8	6.6	36.5	248.1	1221
Ow-12	42	0.3	5.9	42	252	901
Ow-13	14	4	5.8	33.6	230.4	1049
Ow-14	15	0	7.8	29.1	259.7	1069
Ow-15	33	1	5.9	46.3	262.7	1301
Ow-16	59	16	6.8	37.4	287	1304
Ow-17	12	0.1	6.8	33.2	275.4	1234
Ow-18	37	2	7.8	42.2	260	1407
Ow-19	21	1	6.8	63.9	341	2484.6
Ow-20	25	2	5.8	37.3	285	1406
Ow-21	16	1	5.8	31	267	1394
Ow-22	17	6	5.8	34	269	1404
Ow-23	11	2	5.6	33.2	243	1330
Ow-24	28	3	5.8	50.5	287	1600
Ow-25	13	8	5.3	29.1	280	1600
Ow-26	35	15	6.0	40.0	286	1607

3.5 Turbine

Each turbine is of a single flow 4-stageimpulse condensing type and rotates at 3,000 revolutions per minute.

Turbine speed control and protection:-

The turbine is provided with two mechanical speed governors which keep the speed at 3,000 ± 4% and two emergency stop valves. In case the turbine over speeds or experiences an axial thrust or a drop in bearing lubricating oil pressure or low condenser vacuum below a predetermined value, protective devices will command the governor and emergency stop valves to shut and stop steam supply hence stopping the turbine.

Steam condenser and gas extraction system:-

In order to increase enthalpy drop and subsequent power output, the turbine exhaust pressure must be reduced as much as possible To achieve this end, steam exhausted from turbine is passed into a condenser situated below the turbine. In this chamber, a number of nozzles spray cold water on the steam and the latter condenses into warm water. At a rated power output of 15MW, 134 tonnes of hot water (at 50°C) are formed and discharged from the condenser into a hot water collecting tank (seal pit) through a barometric pipe. In a separate compartment of the same chamber gas/vapor mixture is cooled. The gases which include hydrogen sulphide and carbon dioxide are sucked and thrown out to the atmosphere by two steam-jet gas ejectors. After discharging gases and water from the condenser, a turbine exhaust pressure of about 96mm Hg abs is achieved.

Cooling and circulating water system:-

Pumps installed at the three hot water collecting tanks pump about 7,860 tonnes of water per hour through a common pipe to three mechanically induced draft cooling towers. The warm water is distributed on the top of the cooling towers from where it drops down through wooden splash bars and exchange heat with cold air being fanned up by fans and flowing counter to it. About 50% of that water is lost at the cooling tower though evaporation.

The cold water (at 23 ºC) is siphoned from the cooling tower basin to the condensers by the pressure difference between atmospheric pressure and condenser vacuum.

The flow of water from each cooling tower is approximately 2,340m³/h. A portion of this water is tapped off from the main pipe and pumped through generator air coolers and bearing lubricating oil coolers.

3.6 Generation and transmission

Each turbine drives 19 1875 KVA, air cooled electrical generator. The power produced is passed through switchgear to an 11KV bus bar.4% of that power is used to run the plant auxiliary equipment. One 35 MVA double primary transformer steps up the voltage of the remaining power from11 to 132KV.A 132 KV 22km long transmission line from these transformers transmit the station supply to the national grid through the Naivasha sub-station as shown in figure 2.4.

Protection:-

The generators and transformers are protected by a system of relays which besides tripping the equipment in emergency, operate bell and buzzar alarms.

Control room

All important control and supervisory instruments are centralized in a control room for ease of operation. Schematic diagrams displayed on turbine-generator panels show clearly the plant features and operating conditions of turbo-generator, auxiliary equipment and steam supply system.

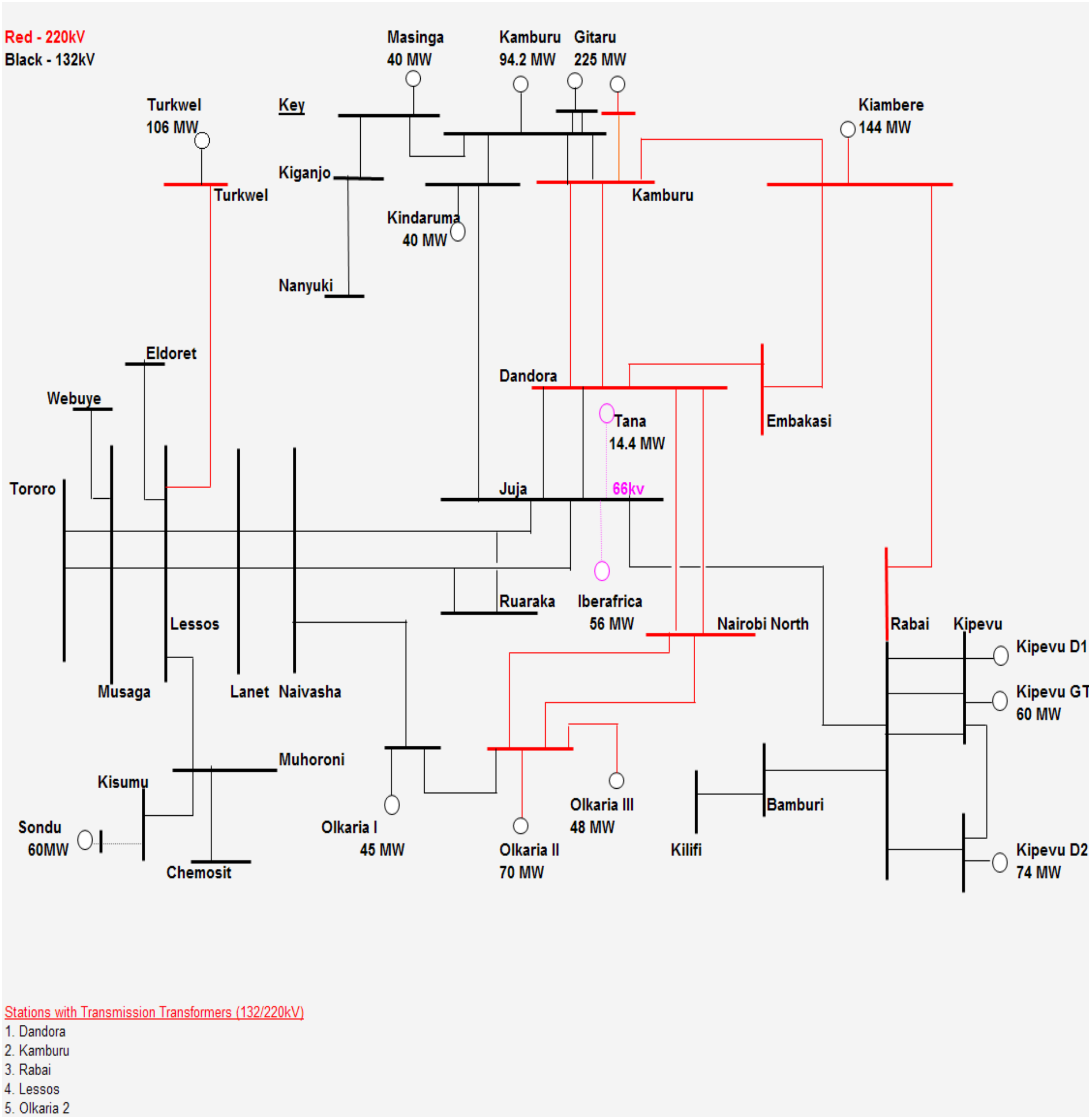

Figure 3.4 Kenya National power grid system

3.7 Geothermal power technology

Geothermal power production involves various methods. Utility-scale geothermal power production employs three main technologies. These are known as dry steam, flash steam and binary cycle systems. The technology employed depends on the temperature and pressure of the geothermal reservoir. Unlike solar, wind, and hydro-based renewable power, geothermal power plant is independent of fluctuations in daily and seasonal weather.

Dry steam

Dry steam power plants use very hot water (>455 F, or >235 ºC) from the geothermal reservoir .The steams goes directly through a pipe to a turbine to spin a generator that produces electricity .This type of geothermal power plant is the oldest, first being used at Lardarello, Italy, in 1904.Fingure 2 is a schematic of a typical dry steam power plant.

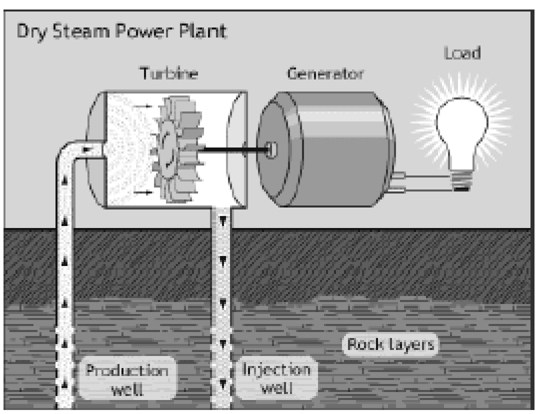

Figure 3.5: Dry steam power plant schematic

Flash steam

Flash steam power plants use hot water (>360 degrees F, or>182 degrees C) from the geothermal power plant. when water is pumped to the generator, it is released from the pressure of the deep reservoir .The sudden drop in pressure causes some of the water to vaporize to steam, which spins the turbine to generate electricity.

Both dry and flash steam power plants emit small amounts of carbon dioxide, nitric oxide, and sulfur. Hot water not flashed into steam is returned to the geothermal reservoir through injection wells

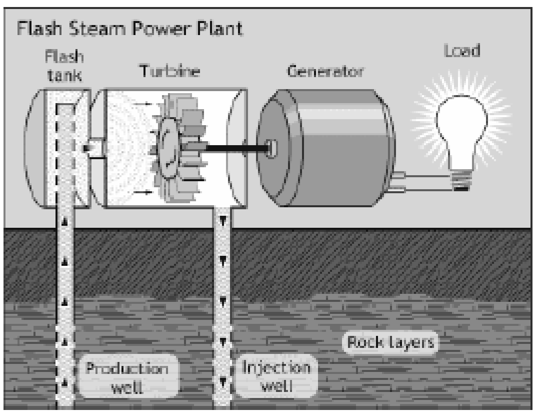

Fig 3.6: Flash steam power plant schematic

Binary –cycle

Binary cycle power plants use moderate-temperature water (107 ºC-182 ºC) from the geothermal reservoir. In binary systems, hot geothermal fluids are passed through one side of a heat exchanger to heat a working fluid in a separate adjacent pipe. The working fluid with a low boiling point like butane or Iso-pentane is vaporized and passed through a turbine to generate electricity. Advantages of binary cycle system are that the working fluid boils at a lower temperature as water does, so electricity can be generated from reservoirs with lower temperature. This cycle is self-contained and produces no emissions. Binary systems should be the dominant geothermal power plant in future.

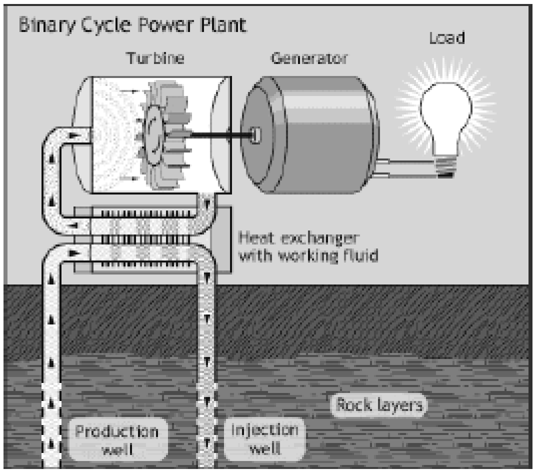

Figure 3.7: Binary cycle schematic power plant

CHAPTER FOUR: GENERATION COST AND THE CURRENT STATUS OF GEOTHERMAL DEVELOPMENT;

Introduction

The cost benefit analysis of a particular source of energy determines its priority in providing electrical energy to the consumers. In order to provide a frame of reference against which to assess the value of the various generating costs, we examine the elements that make up the cost.

4.1 Components of annual costs.

The total annual cost may be broken down into the following components

Fixed costs

This forms the main component in the cost of the generating sources and comprise

(a) Interest on capital, taxes and insurance

(b) Capital cost of the plant

(c) Depreciation charges on the capital costs

(d) Salaries and management

The interest charges on the initial capital expenditure together with other fixed charges such as insurance, rates, taxes usually form 60% to 70% of the total cost of power and are independent of the output.

Running costs

These are variable costs and vary some which with output. Running costs include the following components:

(a) Operation costs including salaries and wages

(b) Maintenance and repairs

(c) Capital

The capital expenditure include the following items

(a)Preliminary survey, investigation cost

(b) Cost of detailed survey and sub-surface exploration

(c) Purchase of land and compensation to property owners for disturbance or loss of amenity

(d) Cost of preparation of detailed design real construction and supervision

(e) Cost of testing material of construction and carrying out experimental works and model tests on design

(f) Actual cost of construction and purchase and installation of equipment

Interest rates

Interest rates payable on capital depends on the following factors

(a) The credit or standing of the borrower, the nature of security offered and the degree of risks involved

(b) The method of finance, whether the whole or part of the capital is borrowed on security or whether it is raised as equity implying an element of specification

(c) The interest rates ruling at the time in the country in which the money has to be raised

Depreciation and obsolescence charges

From the moment a piece of machine is put into service, it begins to wear out. The depreciation charges are meant to take care of repairs and maintenance or total replacement at the end of its useful life.

Obsolescence is defined as the loss of usefulness or economic value which arises from changing conditions or from scientific progress leading to the development of equipment or methods which provide same services more efficiently and at lower cost.

Other factors affecting the cost of power

(a) Load factor

This is the ratio of the average load to the maximum load on the system during the period in consideration. It's the measure of the extend to which the necessary total investment is being utilized. The lower the load factor means that the production is more expensive and the returns are less hence the more the cost of electrical energy. High load factor means better utilization of the installed capacity hence better use of the capital expenditure on plant thus the cost is low. Load factor can be improved by additional of industrial load.

(b) Number of units installed

In deciding the number and size of units to be installed, reliability and economics of the plant must be taken into account. It is necessary to have more than one unit installed, one being for emergency cases. This increases the expenses since not all the installed capacities are put in use. Also the capital cost of a large number of units is maintained and increases with increase in the number of units.

(c) Base load and peak load.

Base plants operate practically all the year round and therefore have high load factor. Peak load plants operate during the peak time to meet the short period peak demand experienced by the supplying system.

Geothermal plant capital cost and operation and maintenance cost were obtained from the Olkaria II geothermal bids.

Table 4.1 Geothermal plant capital cost, operation and maintenance cost

Project name	Olkaria II
Configuration	2×32
Capacity	64 MW
Plant capital ($\$\times10^6$)	173.8
O & M($/KW.yr)	2.0

From the table above the cost of generation for each unit was obtained

Cost of generation of 64 MW $\$173.8\times 10^6$

The cost of Kw $2715.62

The operation and maintenance was valued thus obtained $31.25(kw.yr)

4.2 Current status of geothermal development

Currently, utilization of geothermal energy is only in the Olkaria field. Three of the seven fields namely, Olkaria East field, Olkaria west field and Olkaria Northeast field are generating a total of 127 MWe

In Kenya geothermal is mainly used for power generation from which currently the total output is 130 MW. A very small proportion of geothermal goes into direct use in drying of flowers, greenhouses and balneology.

Due to rapid economic growth, the demand for electricity in the country has increased steadily and in order to meet this demand the rate of developing of additional capacity from geothermal resources has risen. Currently three (3) power plants are in operation in the greater Olkaria covering 750 sq. Km and comprising of Olkaria I, II, III & IV geothermal fields.

Development of geothermal resource is being carried out by the Government, through KenGen (Kenya Electricity Generating Company), and Independent Power Producers (IPPs). Detailed exploration is on-going in other prospects in the Rift Valley so as to rank them for future development.

4.3 Olkaria I Geothermal Field

A total of thirty three (33) wells have been drilled in Olkaria I Geothermal Field which produces 45 MW. Twenty four (24) of the wells are currently connected to the power station while two (2) have been retired. One (1) well is being used for re-injection. Currently the field has steam capable of generating an additional 25 MW.

The plant has three (3) single flow 4-stage turbines, which operate at a steam inlet pressure of five (5) bars absolute and a saturation temperature of 152^{o}C. The turbines have a specific steam consumption of 9.2 tones per hour for each megawatt produced. Since commissioning, the plant has had an average availability and load factor of 98 percent.

The power generated is connected to the national grid via a 22 kilometer 132 kV transmission line to the Naivasha sub-station on the Jinja-Nairobi transmission line.

Figure 4.1: View of Olkaria I Power Plant

4.4 Olkaria II Geothermal Field

The area of this field is about 8.8 Km.Sq, with a total of twenty two (22) wells supplying steam to the power station. Olkaria II Power station, with a capacity of 70 MW, is currently Africa's largest geothermal power station. Wells supplying steam to the power station were drilled between 1986 and 1993, but construction of the power plant was delayed until 2000 when funds were available.

The power plant was commissioned in November 2003. The field has an excess steam capacity capable of generating an additional 28MW. The project was co-financed by the World Bank, the European Investment Bank, KfW of Germany and The Kenya Government.

The plant was designed and constructed using newer technology and is highly efficient in steam utilization. It operates on a single flash cycle with a steam consumption of 7.5 tones per hour for each megawatt generated. All the hot separated brine is continuously re-injected back into the reservoir.

The plant consists of two steam turbo-engines each rated at 35 MW. The turbines are single flow six-stage condensing units with direct contact spray jet condenser. The Power generated is transmitted to the national grid via 220 kV double circuit line to Nairobi. Olkaria II power station is also connected to Olkaria I Power Station by a 132 kV line.

Figure 4.2: View of Olkaria II Power Plant

4.5 Olkaria III Geothermal Field

This is the first power plant in Kenya. It is also the first geothermal plant to use binary technology in the country. Out of the seven wells drilled between 1983 and 1997, five wells were able to discharge steam with an output capacity ranging from 1MW to 4MW.

In 1997, ORMAT International was licensed by the Kenya Government to generate 48 MW from Olkaria III. In August 2000, the international company, through its local subsidiary OrPower 4, commissioned 8MW that was later increased to 12MW from a combined binary cycle pilot plant. As part of its first phase of development, OrPower 4 drilled nine directional wells to further appraise the Olkaria III field.

Following the appraisal program, construction of an extra 35MW unit commenced and is now on the completion stage and was lined up for commissioning during October 2008. As the tender for Olkaria III Geothermal Field was floated for development of a power plant of between 64MW to100 MW, OrPower 4 has been requested to do more geological work with a view to double the existing capacity.

As part of the first phase, nine new wells have been drilled to further appraise the Olkaria III field. Following this appraisal programme, ORMAT has projected that it will be capable of producing 48 MWe over the next 20 years.

Figure 4.3: views of Olkaria III Power Plant

4.6 Olkaria IV Geothermal Field

Between 1992 and 1993, detailed surface exploration was carried out in olkaria IV.This led to siting and drilling of three (3) exploration wells each to a depth of about 2,200 metres. Six appraisal wells have been drilled over an 8 Km^2 field with steam output equivalent to between 4MWe to 5MWe per well. Drilling of production wells is continuing for establishment of first, a 70MWe power plant which will later be upgraded to 140 MWe by 2012.

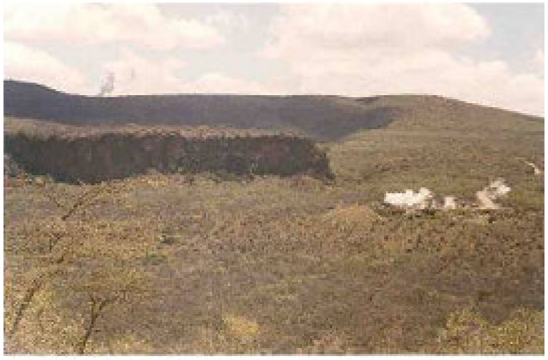

Figure 4.4: A view of Olkaria IV

4.7 Other fields

Eburru

The Eburru geothermal field is located about 50Km north of the Olkaria field. Six wells were drilled in this field between 1988 and 1990.Three of the wells are capable of supporting a plant generating 6MWe i.e. 2.4MWe,1MWe and 2.9MWe.From available scientific data the 2 Sq.km high temperature zone in this field can support a 20MWe power station. A revisit of exploration work has been programmed in order to site areas for directional drilling in the densely fractured Eburru prospect. A 2.5MWe pilot plant has been projected for development in Eburrru by KenGen by 2010

Longonot

The longonot geothermal field lies east of the Olkaria Geothermal field. Geological, geochemical and geophysical surveys were carried out in the prospect in 1988.Results from these surveys were used to site two exploratory wells. The prospect is believed to be more than 60.km² and is capable supporting a 200MWe power plant. A 70MWe power plant will be developed in Longonot and commissioned in 2012.An additional 70MWe plant will be developed in the field for commissioning by 2015.

Suswa

The Suswa geothermal prospect is located South East of the Olkaria geothermal field. Detailed geoscientific studies carried out between 1992 and 1993 rated the field as having a good potential for geothermal development. There is a shallow heat source under the caldera at a depth of about 10 Km. Three wells have been sited on the main caldera floor. It is estimated that more than 200 MWe can be generated from this prospect. A 70MWe power plant is programmed for development and commissioning in 2016.Aprivate investor has been licensed to carry out further survey and subsequent development, subject to a specific time bound programme.

Menengai

Menengai Geothermal prospect lies to the north of Nakuru town and extends to the south of Kisanana. Studies carried in 2003 and 2004 indicate the existence of a geothermal system under the Menengai caldera. It is estimated that the high temperature part of the resource covers 48 Sq. km and has an estimated potential for generating 720MWe.Three deep exploratory wells were sited within the caldera floor. It is lined up for development of a 140MWe power plant by the year 2014.

Oserian power plant

This is a binary power plant owned by Oserian flower farm. It was commissioned in July 2004 where its steam well was leased from Kengen. It generates 2 MW

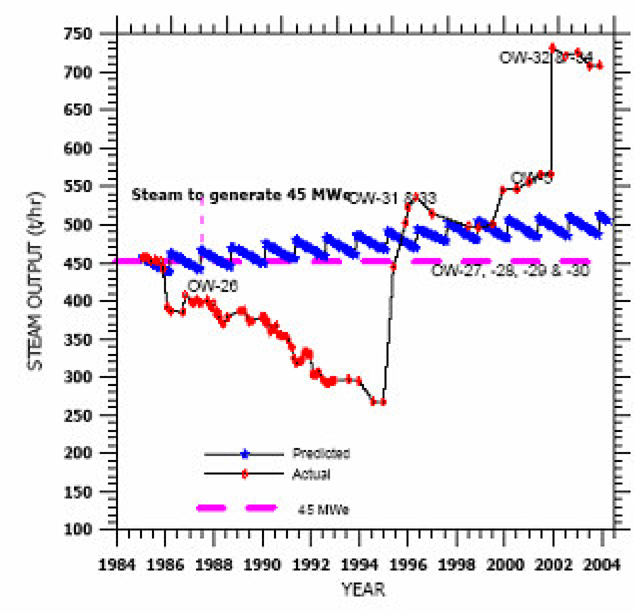

Figure 4.5: Steam output at Olkaria East field for 23 years

CHAPTER FIVE: FUTURE DEVELOPMENTS

5.1 Future investment opportunities

Due to rapid economic growth, the demand of electricity has steadily continued to rise. In order to meet this demand the rate of developing additional electricity from geothermal resources should continue to increase. This will therefore provide opportunity for investment in development of geothermal resources by interested parties. The likely order of development of the geothermal resources is as shown in table below.

Table 5.1: Proposed sequence for geothermal development in the short to medium term

Project	Planned generation (MWe)	Year to be commissioned
Olkaria III	35	2008 (Oct.)
Olkaria II	35	2010
Eburru	2.5	2010
Olkaria IV	140	2012
Longonot I	70	2012
Menengai I	70	2013
Menengai II	70	2014
Longonot II	70	2015
Suswa I	70	2016
North Rift I	70	2017
North Rift II	70	2018

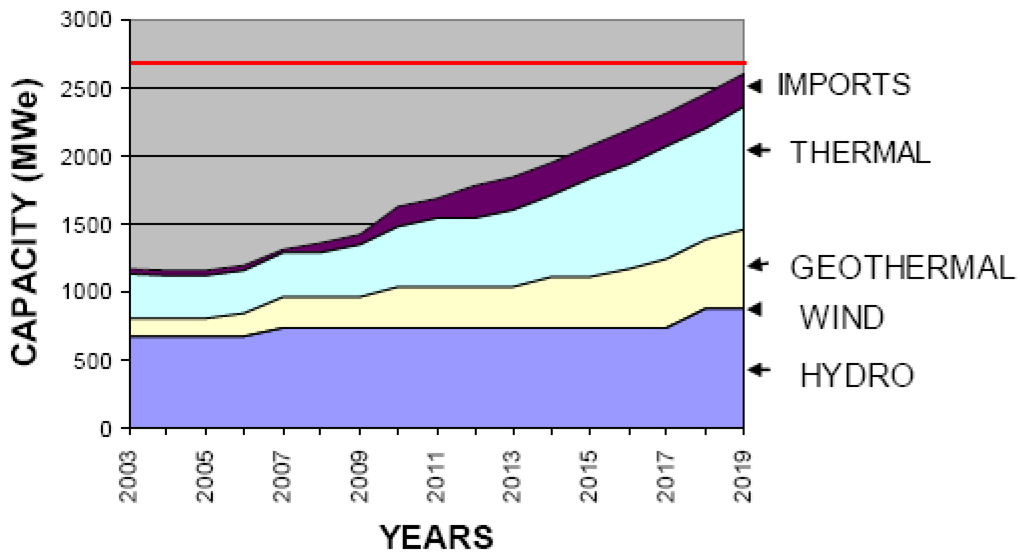

Figure 5.1 A graph of the projected future demands and power sources.

Renewable energy technology is continuously evolving with the goal of reducing risk and lowering cost. The goal of geothermal industry is to achieve a geothermal energy life-cycle. To achieve this goal, other types of nontraditional resources and experimental systems are being explored like hot dry rock resources, improved heat exchangers, and improved condenser efficiency.

Table 5.2 Projected future power demands and sources

Phase	Plant IV (Domes) (GoK/KfW)		Plant V (Longonot) (ARGEO/GoK)		Plant VI (Suswa) (ARGEO/GoK)		Plant VII (Menengai) (BGR/GoK)		Plant VIII (Olbanita) (BGR/GoK)		Plant IX (Arus)	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
Surface Exploration	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Jan 2004	Apr 2004	Jan 2005	Apr 2005	Jan 2006	Apr 2006
Exploration drilling	done	done	May 2005	Nov 2005	Dec 2005	Jul 2006	Apr 2008	Nov 2008	[illegible] 2010	[illegible]	[illegible]	[illegible]
Appraisal Drilling	Mar 2004	Jan 2007	Aug 2006	Jun 2008	Jan 2009	Jan 2010	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Apr 2017
Production drilling	Jan 2007	Aug 2008	Feb 2010	[illegible]	[illegible]	[illegible]	Oct 2013	Jan 2016	Sep 2016	Oct 2018	Apr 2017	May 2018
Steam gathering networks	July 2007	Aug 2009	[illegible]	[illegible]	[illegible]	[illegible]	May 2014	Jun 2016	Sep 2016	Apr 2019	Nov 2017	Nov 2019
Plant construction	Jan 2008	Jan 2010	Sep 2010	Sep 2012	Jan 2013	Feb 2015	Oct 14	Nov 2016	Mar 2017	Apr 2019	May 2020	Jun 2022
Plant	Jan 2010		Sep 2012		Feb 2015		Nov 2016		Apr 2019		Jun 2022	

Resource conceptual definition

Confirmation by Drilling

Resource Sizing

Power Plant and Steam Field Development

5.2 Future geothermal development activities

5.2.1 Hot dry rock

Hot dry rock geothermal technology offers enormous potential for electricity production. These resources are much deeper than hydrothermal resources and come from relatively water free hot rock found at a depth of 4000 meters or more beneath the Earth's surface. Energy is extracted by circulating water through man-made fractures in the hot rock. Heat is then extracted from the water at the surface for power generation, and the cooled water is then recycled through fractures to pick up more heat, creating a closed-loop system. Hot Dry Rocks resources are much deeper than hydrothermal resources hence much more expensive to develop.

5.2.2 Heat exchanger liners

The highly corrosive nature of geothermal plants poses a challenge to heat exchangers by reducing their thermal conductivity. Research is currently being conducted to replace the use of expensive heat exchanger materials such as stainless steel and titanium, with new, less expensive polymer –base coated carbon steel. The polymer-base-coated carbon steel is proving to be as resistive to corrosion as the conventional, expensive materials.

5.2.3 Air-cooled condensers

Currently, the National Renewable Energy Laboratory (NREL) is investigating ways to improve the efficiency of air cooled condensers that are commonly used in binary cycle geothermal plants. Air-cooled condensers use large airflow rates to lower the temperature of the gas once it has passed through the system to produce condensation. The fluid is then collected and returned to the cycle to be vaporized. This cycle is important in binary cycle geothermal plants because of the lack of make-up water. To increase the heat exchange efficiency, NREL is currently testing the use of perforated fins in the condensers, with all the air flowing through perforations, to increase heat exchange and therefore, condensation. As technological improvements continue to be discovered and more geothermal plants are brought online, geothermal generating capacity will continue to increase.

5.3 Future plans

(a)Construction of a 2.5 MW Plant and its expansion in future.

(b)Extensive surface exploration

(c)Prioritization of fields as they are explored.

(d)Critical is exploration drilling funding.

(e)Pilot plant if exploration strikes steam.

(f)Carbon credits funding under Kyoto protocol.

(g)Carry prioritization of Menengai, Suswa and Longonot with BGR.

(h)Targeting ARGeo funding

CHAPTER SIX: OTHER USES AND IMPACTS OF GEOTHERMAL ENERGY

6.1 Direct uses of geothermal energy.

(a) Green house heating

Oserian Flower Company utilizes both the geothermal hot water and the carbon dioxide from the steam in growing the flowers as shown in the figure below. The company has currently expanded from 3 to 30 hectares of land and it is planning to lease more wells from KENGEN for this purpose

Figure 6.1; Greenhouse heating

.(b) Hot springs are used to heat spas in tourist hotels for e.g. in L.Bogoria hotel

Figure 6.2; Recreation applications for Geothermal energy

(C) At Eburru, geothermally heated flowers are used to dry pyrethrum flowers.

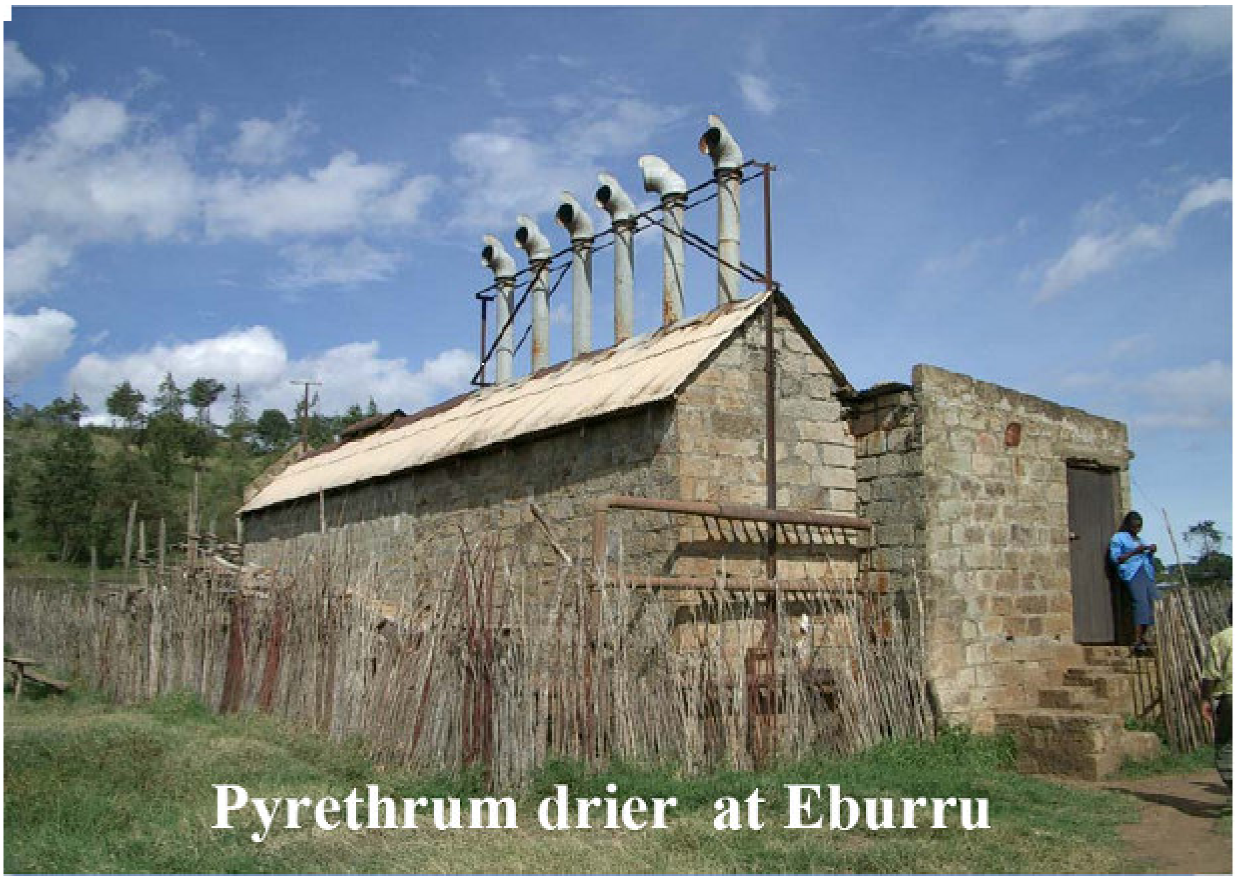

Figure 6.3: Pyrethrum drier at Eburru

(d) The local community at Eburru collects water from steam from fumaroles for domestic use.

Figure 6.4: Water harvesting at Eburru

6.2 Factors affecting geothermal energy exploration and exploitation

(a)Geothermal power development has been hampered by lack of fund

(b)There has been excessive field exploration by interested developers

6.3 Ways of improving geothermal energy exploration and exploitation

(a)Explore and develop geothermal energy for electricity generation and other uses (b)Remove risk of field of exploration from interested developers

(c)Strengthening of the Geothermal Development Company (GDC)

Planned power additions in the next 5 years: 830 MW

Table 6.1: Planned power additions for 5 years

Geothermal	Hydro	Thermal	Wind	Imports
143.5	120	630.2	30	100
14%	11.7%	61.7%	2.9%	9.8%

6.4 Other prospective areas

(a)Surface studies is expected to be complete by 2010

(b)Suswa, Longonot, Menengai, and Eburru are high temperature (285-300) with low resistivity (10-15 Ohm-m) and heat loses >3000 MW AT 1m depth.

(c)Arus, L.Bogoria and Baringo are low temperature regions with estimated heat lose of 1000-1150 MW at 1 m depth.

(d)Estimated geothermal potential is approximately 700 MW for Menengai, 200 MW (Longonot) and 25MW (Eburru).

(e)Detailed surface exploration has occurred in suswa-1993, Longonot-1998, Menengai-Olbanita-2004, L.Baringo-2004, Arus-L.Baringo-2005, and Koros-chepchuk-2006.

<u>6.5 Advantages of geothermal energy</u>

(a)No foreign currency fuel costs

(b)No need to transport fuel

(C)Relatively little pollution

(d)No mines, oil ports, etc

(e)Waste product disposal is easy and economical

(f)Uses free fuel i.e. steam

(g)No interference with river flows.

(h)No loss of generating capacity during drought years

(i)Geothermal power plants require relatively little land. An entire geothermal field uses only 1-8 acres per MW versus 5-10 acres per MW for nuclear plants and 19 acres per MW for coal plants. Geothermal power plants are clean because they neither burn fossil fuels nor produce nuclear waste. They can be sited in farmland and forests and can share land with cattle and local wildlife ,the Hell's Gate National park in Kenya is established around Olkaria I. Land uses in the park include livestock grazing, growing foodstuffs and flowers, wildlife conservation and birds

6.6 Disadvantages of geothermal energy

(a) High tariffs

The main problem hindering Geothermal Power development is one of high tariffs.

The Government needs to raise funds both internally and through donor support in order to undertake geothermal resource assessment. For tariffs to be low the government needs to undertake exploration, including steam field development. This would leave the IPP' s to undertake plant construction for generating electricity.

(b) Environmental impacts

Geothermal power plants have environmental impacts. These should be balanced against geothermal energy's advantages. The primary impacts of geothermal plant construction and energy production are gaseous emissions, land use, noise, and potential ground subsidence

(i)Gaseous Emissions

Geothermal fluids contain dissolved gases mainly carbon dioxide (CO_2) and hydrogen sulfide(H_2S),small amounts of ammonia, hydrogen, nitrogen, methane and randon .and minor quantities of volatile species of boron, arsenic, and mercury.

Table 6.2: Comparison of CO_2 Emissions by Power Source

Power source	**CO_2 Emissions (lb/kwh)**
Geothermal	0.20
Natural gas	1.321
Petroleum	1.969
Coal	2.095

Hydrogen sulfide emissions create a sulfur smell.

(ii)Noise

Noise occurs during exploration, drilling and construction phases. Noise levels from these operations range from 45 to 120 decibels (dB)..

(iii) Ground subsidence

In early stages of Geothermal development, fluids are withdrawn from a reservoir at a rate greater than the natural flow into the reservoir. This net outflow causes rock formations at the site to compact, particularly in the case of clays and sediments, leading to ground subsidence at the surface. Key factors causing subsidence include:

(a) A pressure drop in the reservoir as a result of fluid withdrawal
(b) The presence of a highly compressible geological rock formation above or in the upper part of a shallow reservoir
(c) The presence of high-permeability paths between the reservoir and the formation, and between the reservoir and the ground surface.

Subsidence is greater in liquid dominated fields because of the geological characteristics associated with the type of field. This subsidence affects the stability of pipelines, drains and well casings. It also causes formation of ponds, cracks in the ground and instability of buildings.

The greatest recorded subsidence occurred in Wairakei in New Zealand where the ground subsided by 13 meters which led to creation of 1 Km pond, cracking of a nearby highway, compressive buckling and tensile fracturing of steam pipelines and fissures occurred in the surrounding fields.

6.7 Ways of reducing geothermal effects

(a) Mitigate subsidence effects can be prevented by maintaining pressure in the reservoir. Fluid re-injection help to reduce pressure drop but its effectiveness depends on where the fluid is re-injected and the permeability conditions in the field. It should be done at some distance from the production well to avoid the cooler rejected waste fluid from lowering the temperature of the production fluid and may not help in preventing subsidence

(b) Site workers can be protected from excessive noise by wearing ear mufflers. Noise levels should be kept below 65 Db.

. (c) According to Geothermal Energy Association, improved and increased injection to sustain geothermal reservoirs has helped reduce carbon dioxide emissions from geothermal power plants.

(d)Hydrogen sulphide emissions are removed through a process called stretford, which produces pure sulphur thus reducing H_2S emissions by more than 90%.The hydrogen sulphide can also be burned to produce sulphur dioxide, which can be dissolved, converted to sulphuric acid and sold to provide income.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

(a) Kenya relies on biomas as the primary source of energy where Electricity accounts to 15%, Hydropower dominates electricity sector (62%) followed by fossil fuels.

(b) Geothermal exploration has been hampered by lack of funds.

(c) Initiatives like ARGeo and other donor funding agencies augmented with local funding can accelerate geothermal exploitation.

(d) In Kenya, creation of GDC will accelerate geothermal development.

(e) Due to changing weather patterns, geothermal power is the best way to go for countries with the potential.

(f) Kenya plans to generate additional 576 MW from geothermal sources by the year 2026.

(g)Geothermal energy exploitation has increased by 280% from 45MW in 1999 to 127 MW in 2004.

(h) In the power development plans of year 2003-2004 geothermal energy has been considered as the least cost source of electrical power.

(i) Oserian development company, which is a flower developing company has started utilizing geothermal steam for geothermal heating. Oserian has also constructed 1.8 MW binary plant Ormat OEC for use in the farm activities.

(j) There is an enormous amount of geothermal energy in the Kenyan rift valley which should be exploited to replace the fossil fuel plants

(k) Geothermal energy is indigenous, low cost and environmentally benign source of energy and should be given the first priority whenever it occurs.

(l) Creation of a special purpose geothermal development company by the government will be a useful milestone in Geothermal energy exploitation and is expected to accelerate geothermal development in Kenya to achieve the least cost development plan.

(m) Since 2000, OrPower inc. have been generating 12 MW from an early generation Ormat plant in Olkaria west field. They have drilled more wells and obtained enough steam to generate 36 MW over the next 25 years. Plans are underway to construct the additional power plant.

7.2 RECOMMENDATIONS

My intention has been to provide Kenyans with a balanced overview of the utility scale geothermal power believe that clean reliable power can be developed from renewable sources, with geothermal power making an important contribution. I would advise Kenyans to gain a deeper understanding of the potential of geothermal power and the issues surrounding its development. I urge the government to seek further understanding of these issues through research and the means to their resolution, in order to support the progress of geothermal energy in providing clean, reliable, and economic power.

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