DEDICATION

I dedicate this to my dearest family: Dominic my father, Mary my mother, brothers: Cyprian, Polycap and Ken, Sisters: Lily, Lilo, Bena, Perpetua, Felistus, Valerie and the late Clare.

ACKNOWLEDGEMENTS

I want to greatly appreciate the support of my supervisor Dr. Wekesa. Your tutoring in developing this manuscript has been nothing but motivational.

I also want to register my sincere appreciation to my classmates for the moral and material support accorded to me during the whole project time.

Last but not least I want to thank the Department of Electrical and Information Engineering under the leadership of Dr. Oduol for the undying support I was given.

DECLARATION AND CERTIFICATION

This BSc. work is my original work and has not been presented for a degree award in this and/or any other university.

é é é é é é é .é é é é é

WAFULA ANTHONY MARK F17/1776/2006

This report has been submitted to the Dept. of Elect and Info Engineering, University of Nairobi with my approval as supervisor:

é é é é é é é é é é é é

Dr. CYRUS WEKESA

Date: é é é é é é é é é é

Table of Contents

ABSTRACT

Renewable energy is that which is naturally replenished. Generally mainstream forms of renewable energy are: wind power, hydropower, solar energy, biomass, biofuels, and geothermal power.

Geothermal energy is thermal energy stored and generated within the earth. The first geothermal power plant was installed in Larderello in Italy and a second one in Wairekei in new Zealand in the early 1900ǿs. Geothermal energy production has since grown over the years and as at 2010, according to the International Geothermal Association **(IGA)**, over 10,000 MW had been exploited. Its potential in the world currently stands at 67,000 gigawatts (according to **IGA**).

In Kenya the first geothermal power plant was commissioned in the early 1980ǿs at Olkaria with a capacity of 15 MW. Kenya was the first country in Sub-Saharan Africa to exploit geothermal based power on a significant scale. As current statistics say, Kenya has so far managed to currently exploit almost 200 MW of geothermal power. The major producing plants are: Olkaria I, Olkaria II, Olkaria III, and Olkaria IV. Statistics state that Kenya has a vast geothermal power potential of over 7,000 MW in the Rift Valley region. Over 14 sites have so far been explored and others are the process of being explored.

Looking at Kenyaǿs current energy profile, hydro power dominates by a strong 50%. The government has instituted mechanisms to woo private investment into geothermal power production. The mechanisms which include tax incentives, giving investment guarantees, establishment of National Energy Advisory Council among others coupled with good governance are spurring growth in this sector.

With water catchment areas depleting due to human encroachment, recurring low levels of water at the dams there is a need to diversify. Geothermal power is the other vast endowment, cost effective and environment friendly solution that needs to be exploited.

CHAPTER ONE: INTRODUCTION

1.1 Preamble

It is increasing becoming an issue of great importance for countries to venture into exploitation of renewable energy. This is necessitated by the fact that power demands are increasing against the backdrop of threatened conventional power generation sources e.g hydro. Geothermal energy is one of the largest available renewable energy sources which can cushion against a possible future energy crisis.

1.2 Problem statement:

It is required to assess the potential of Kenyaôs geothermal energy using available statistics and state its effect on Kenyaôs current power position.

1.3 Objectives:

i. To look into the various available forms of renewable energy.
ii. To define geothermal energy and give various types of geothermal power plants.
iii. To identify Kenyaôs geothermal power potential.
iv. To identify using findings from (iii) above how geothermal energy can alleviate Kenyaôs power shortfalls.

1.4 Project report layout

The report is has been divided into 3 main sections:

a) Chapter one handles the introductory part.
b) Chapter two deals with literature review.
c) Chapter three sums up discussions, conclusion and recommendation for further work.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Renewable Energy

2.1.1 Definition

Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished).

While many renewable energy projects are large-scale, renewable technologies are also suited to rural and remote areas, where energy is often crucial in human development. [1] Globally, an estimated 3 million households get power from small solar PV systems. Micro-hydro systems configured into village-scale or county-scale mini-grids serve many areas. [2] More than 30 million rural households get lighting and cooking from biogas made in household-scale digesters. Biomass cook stoves are used by 160 million households. [2]

Climate change concerns, coupled with high oil prices, peak oil, and increasing government support, are driving increasing renewable energy legislation, incentives and commercialization. [3] New government spending, regulation and policies helped the industry weather the global financial crisis better than many other sectors. [2]

2.1.2 Applications of renewable energy where conventional fuels are involved

Renewable energy replaces conventional fuels in four distinct areas*:* ***power generation***, ***hot water/ space heating***, ***transport fuels***, and ***rural (off-grid) energy services***: [2]

2.1.2.1 Power generation.

Renewable energy provides 18 percent of total electricity generation worldwide. Renewable power generators are spread across many countries, and wind power alone already provides a significant share of electricity in some areas: for example, 14 percent in the U.S. state of Iowa, 40 percent in the northern German state of Schleswig-Holstein, and 20 percent in Denmark. Some countries get most of their power from renewables, including Iceland (100 percent), Brazil (85 percent), Austria (62 percent), New Zealand (65 percent), and Sweden (54 percent). [2]

2.1.2.2 Heating.

Solar hot water makes an important contribution in many countries, most notably in China, which now has 70 percent of the global total (180 GWh). Most of these systems are installed on multi-family apartment buildings and meet a portion of the hot water needs of an estimated 50ï 60 million households in China. Worldwide, total installed solar water heating systems meet a portion of the water heating needs of over 70 million households. The use of biomass for heating continues to grow as well. In Sweden, national use of biomass energy has surpassed that of oil. Direct geothermal for heating is also growing rapidly. [2]

2.1.2.3 Transport fuels.

Renewable biofuels have contributed to a significant decline in oil consumption in the United States since 2006. The 93 billion litres of biofuels produced worldwide in 2009 displaced the equivalent of an estimated 68 billion liters of gasoline, equal to about 5 percent of world gasoline production. [2]

2.1.2.4 Rural (off grid) energy services:

This is where a small power generating plant provides services to consumers within the locality where it is built directly without being connected to the main grid.

2.1.3 Mainstream forms of renewable energy

2.1.3.1 Wind power:

Energy received from the movement of the wind across the earth. This energy is a result of the heating of our oceans, earth, and atmosphere by the sun.

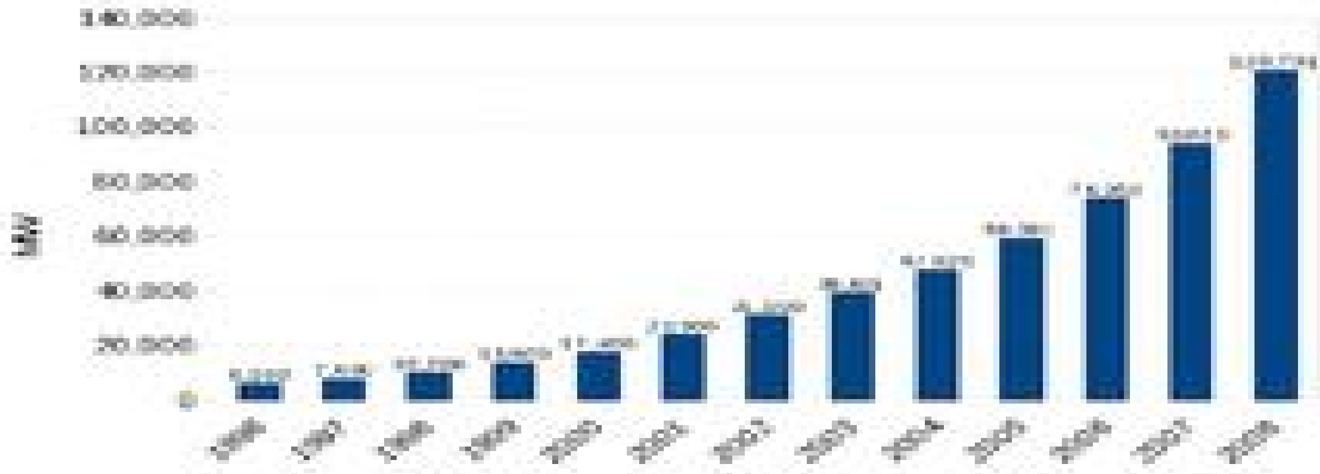

*Fig 1.0. Wind power: worldwide installed capacity 1996-2008(Source-*EWEA Executive summary "Analysis of Wind Energy in the EU-25" (PDF)*)*

The adoption of wind power has been increasing.

Airflows can be used to run wind turbines. Modern wind turbines range from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5ï 3 MW have become the most common for commercial use; the power output of a turbine is a function of the cube of the wind speed, so as wind speed increases, power output increases dramatically. [4] Areas where winds are stronger and more constant, such as offshore and high altitude sites are preferred locations for wind farms. Typical capacity factors are 20-40%, with values at the upper end of the range in particularly favorable sites.

Globally, the long-term technical potential of wind energy is believed to be five times total current global energy production, or 40 times current electricity demand. This could require large amounts of land to be used for wind turbines, particularly in areas of higher wind resources. Offshore resources experience mean wind speeds of approximately 90% greater than that of land, so offshore resources could contribute substantially more energy.

Wind power is renewable and produces no greenhouse gases during operation, such as carbon dioxide and methane.

2.1.3.2 Hydropower:

This is power that is derived from the force or energy of moving water, which may be harnessed for useful purposes.

Fig 1.1 *Grand Coulee Dam: (Source-Google images)*
A hydroelectric gravity dam on the Columbia River in the U.S. state of Washington. The dam supplies four power stations with an installed capacity of 6,809 MW and is the largest electric power-producing facility in the United States.

Energy in water can be harnessed and used. Since water is about 800 times denser than air, even a slow flowing stream of water, or moderate sea swell, can yield considerable amounts of energy.

2.1.3.3 Forms of water energy:

Hydroelectric energy is a term usually reserved for large-scale hydroelectric dams. Examples are the ***Grand Coulee Dam*** in Washington State and the ***Akosombo Dam*** in Ghana.

Micro hydro systems are ***hydroelectric power*** installations that typically produce up to 100 kW of power. They are often used in water rich areas as a ***remote-area power supply*** (RAPS). There are many of these installations around the world, including several delivering around 50 kW in the ***Solomon Islands*** in the east of Papua New Guinea.

Damless hydro systems derive ***kinetic energy*** from rivers and oceans without using a dam.

Ocean energy describes all the technologies to harness ***energy*** from the ***ocean*** and the ***sea***. This includes ***marine current power, ocean thermal energy conversion,*** **and *tidal power.***

2.1.3.4 Solar energy

Solar energy is the energy derived from the sun through the form of solar radiation. Solar powered electrical generation relies on photovoltaics and heat engines. A partial list of other solar applications includes space heating and cooling through solar architecture, day lighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes.

Fig 1.2 Monocrystalline solar cell. (Source-google images)

Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

2.1.3.5 Biomass

Biomass (plant material) is a renewable energy source because the energy it contains comes from the sun. Through the process of photosynthesis, plants capture the sun's energy. When the plants are burned, they release the sun's energy they contain. In this way, biomass functions as a sort of natural battery for storing solar energy. As long as biomass is produced sustainably, with only as much used as is grown, the battery will last indefinitely. [5]

In general there are two main approaches to using plants for energy production: growing plants specifically for energy use, and using the residues from plants that are used for other things. The best approaches vary from region to region according to climate, soils and geography. [5]

2.1.3.6 Biofuels

They are a wide range of fuels which are in some way derived from biomass. The term covers solid biomass, liquid fuels and various biogases.

Fig 1.3 Information on pump regarding ethanol fuel blend up to 10%, California.(Source-google images)

Liquid biofuel is usually either bioalcohol such as bioethanol or an oil such as biodiesel.

Bioethanol is an alcohol made by fermenting the sugar components of plant materials and it is made mostly from sugar and starch crops. With advanced technology being developed, cellulosic biomass, such as trees and grasses, are also used as feedstocks for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil.

Biodiesel is made from vegetable oils, animal fats or recycled greases. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using transesterification and is the most common biofuel in Europe.

Biofuels provided 1.8% of the world's transport fuel in 2008. [6]

2.1.3.7 Geothermal Energy

Geothermal energy is energy obtained by tapping the heat of the earth itself, both from kilometers deep into the Earth's crust in volcanically active locations of the globe or from shallow depths, as in geothermal heat pumps in most locations of the planet. Ultimately, this energy derives from heat in the Earth's core.

Fig 1.4 Krafla Geothermal Station in northeast Iceland (Source-google images)

.

Three types of power plants are used to generate power from geothermal energy:

- ***dry steam,***
- ***flash steam,***
- ***binary cycle***.

Dry steam plants take steam out of fractures in the ground and use it to directly drive a turbine that spins a generator.

Flash plants take hot water, usually at temperatures over 200 °C, out of the ground, and allows it to boil as it rises to the surface then separates the steam phase in steam/water separators and then runs the steam through a turbine.

In binary plants, the hot water flows through heat exchangers, boiling an organic fluid that spins the turbine. The condensed steam and remaining geothermal fluid from all three types of plants are injected back into the hot rock to pick up more heat. (**Renewable energy institute**)

2.1.3.8 New and emerging renewable energy technologies

New and emerging renewable energy technologies are still under development and include cellulosic ethanol, hot-dry-rock geothermal power, and ocean energy. These technologies are not yet widely demonstrated or have limited commercialization. Many are on the horizon and may have potential comparable to other renewable energy technologies, but still depend on attracting sufficient attention and research, development and demonstration (RD&D) funding. [2]

2.1.3.8.1 Cellulosic ethanol

Is a biofuel produced from wood, grasses, or the non-edible parts of plants.

It is a type of biofuel produced from lignocelluloses, a structural material that comprises much of the mass of plants. Lignocelluloses is composed mainly of cellulose, hemicelluloses and lignin. Corn Stover, switch grass, miscanthus, woodchips and the byproducts of lawn and tree maintenance are some of the more popular cellulosic materials for ethanol production.[2]

2.1.3.8.2 Ocean energy

This refers to the energy carried by ocean waves, tides, salinity, and ocean temperature differences. The movement of water in the worldôs oceans creates a vast store of kinetic energy, or energy in motion. This energy can be harnessed to generate electricity to power homes, transport and industries.[2]

The term ocean energy encompasses both wave power ,power from surface waves, and tidal power obtained from the kinetic energy of large bodies of moving water.[2]

2.1.3.8.3 Enhanced Geothermal Systems

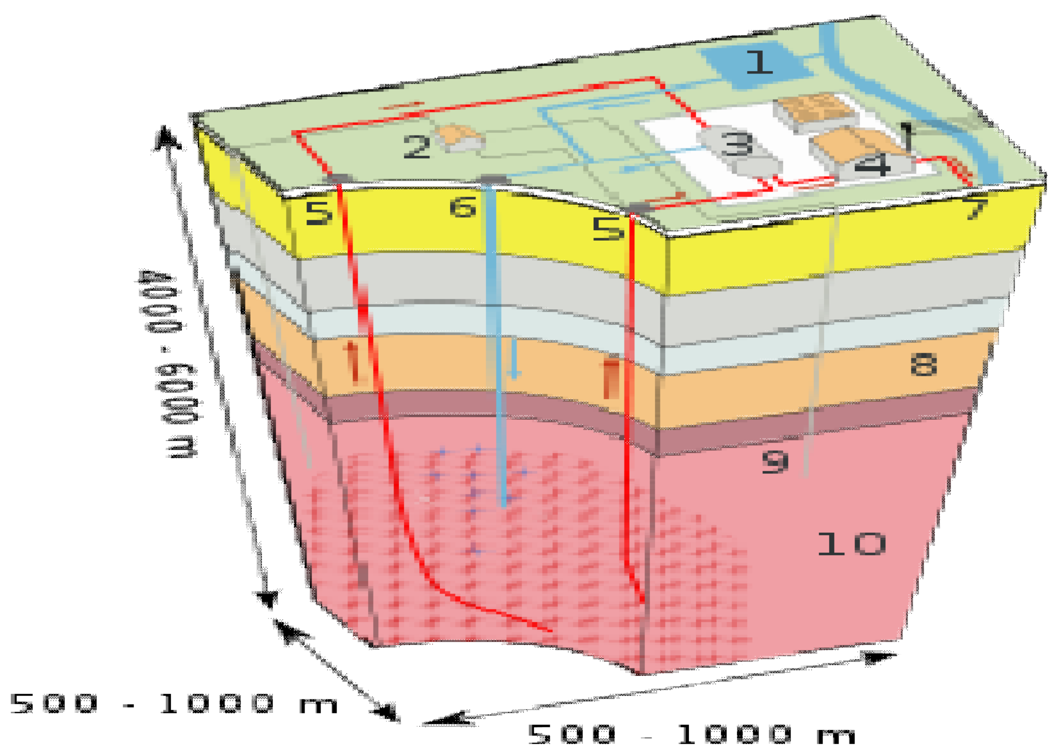

Fig 1.5 Enhanced Geothermal system.(Source- Google images)

Enhanced geothermal system

1:Reservoir 2:Pump house 3:Heat exchanger 4:Turbine hall 5:Production well 6:Injection well 7:Hot water to district heating 8:Porous sediments 9:Observation well 10:Crystalline bedrock

Enhanced Geothermal Systems are a new type of geothermal power technologies that do not require natural convective hydrothermal resources. The vast majority of geothermal energy within drilling reach is in dry and non-porous rock. EGS technologies "enhance" and/or create geothermal resources in this "hot dry rock (HDR)" through hydraulic stimulation.

EGS / HDR technologies, like hydrothermal geothermal, are expected to be base load resources which produce power 24 hours a day like a fossil plant. Distinct from hydrothermal, HDR / EGS may be feasible anywhere in the world, depending on the economic limits of drill depth. Good locations are over deep granite covered by a thick (3ï 5 km) layer of insulating sediments which slow heat loss. [7]

2.1.3.8.4 Nanotechnology thin-film solar panels

Solar power panels that use nanotechnology, which can create circuits out of individual silicon molecules, may cost half as much as traditional photovoltaic cells, according to executives and investors involved in developing the products

2.2 Geothermal energy

2.2.1 Definition

Geothermal energy is thermal energy generated and stored in the Earth. Thermal energy is energy that determines the temperature of matter. Earth's geothermal energy originates from the original formation of the planet, from radioactive decay of minerals, from volcanic activity, and from solar energy absorbed at the surface. The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times, but it is now better known for electricity generation. Worldwide, about 10,715 megawatts (MW) of geothermal power is online in 24 countries. An additional 28 gigawatts of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination and agricultural applications.

2.2.2 Brief history

The first geothermal power station was built at Lardrello, in Italy, and the second was at Wairekei in New Zealand. Others are in Iceland, Japan, the Philippines and the United States. In Iceland, geothermal heat is used to heat houses as well as for generating electricity. If the rocks aren't hot enough to produce steam we can sometimes still use the energy - the Civic Centre in Southampton, England, is partly heated this way as part of a district heating scheme with thousands of customers.

Geothermal energy is an important resource in volcanically active places such as Iceland and New Zealand. How useful it is depends on how hot the water gets. This depends on how hot the rocks were to start with, and how much water we pump down to them. Water is pumped down an "injection well", filters through the cracks in the rocks in the hot region, and comes back up the "recovery well" under pressure. It "flashes" into steam when it reaches the surface. The steam may be used to drive a turbo generator, or passed through a heat exchanger to heat water to warm houses. A town in Iceland is heated this way. The steam must be purified before it is used to drive a turbine, or the turbine blades will get "furred up" like your kettle and be ruined. [9]

Fig 1.6 Larderello Geothermal Station, in Italy (*Source-Google images)*

2.2.3 Thermal energy

2.2.3.1 Definitions

Thermal energy is defined as part of the total internal energy of a thermodynamic system.

Thermal energy is also defined as the total mechanical energy of the particles in a substance. Microscopically, the thermal energy is identified with mechanical kinetic energy of the constituent particles or other forms of kinetic energy associated with quantum-mechanical microstates. The distinguishing difference between the terms *kinetic energy* and *thermal energy* is that thermal energy is the mean energy of disordered, i.e. random, motion of the particles or the oscillations in the system. The conversion of energy of ordered motion to thermal energy results from collisions. [10]

All kinetic energy is partitioned into the degrees of freedom of the system. The average energy of a single particle with f quadratic degrees of freedom in a thermal bath of temperature T is a statistical mean energy given by the equipartition theorem as

$$E_{thermal} = f \cdot \frac{1}{2}kT$$ é é é é é é é é é .(1)

where k is the Boltzmann constant. The total thermal energy of a sample of matter or a thermodynamic system is consequently the average sum of the kinetic energies of all particles in the system. Thus, for a system of N particles its thermal energy is [10]

$$U_{thermal} = N \cdot f \cdot \frac{1}{2}kT.$$ é é é é é é é .(2)

In general, however, $U_{thermal}$ is not the total energy of a system. Physical systems also contain static potential energy, such as chemical energy, or the particle's rest energy due to the equivalence of energy and mass.

2.2.3.2 Thermal energy in an ideal gas

Thermal energy is most easily defined in the context of the ideal gas, which is well approximated by a monatomic gas at low pressure.

The mechanical kinetic energy of a single particle is

$$E_{kinetic} = \frac{1}{2}mv^2$$ é é é é é é é é é é (3)

where m is the particle's mass and v is its velocity. The thermal energy of the gas sample consisting of N atoms is given by:,

$$U_{thermal} = \frac{1}{2}Nm\overline{v^2} = \frac{3}{2}NkT.$$ é é é é é ..(4)

assuming no losses.

Where the line over the velocity term indicates that the average value is calculated over the entire ensemble.. This formalism is the basic assumption that directly yields the ideal gas law, and it shows that for the ideal gas, the internal energy consists only of its thermal energy:

$$U = U_{thermal}$$ é é é é é é é é é é é é é é .(5)

2.2.3.3 Distinction of thermal energy and heat

In engineering and technology heat and *thermal energy* are often indiscriminately used interchangeably.

In thermodynamics, heat must always be defined as energy in exchange between two systems, or a single system and its surroundings Heat is never a property of the system, nor is it *contained* within the boundary of the system.

In contrast to heat, thermal energy exists on both sides of a boundary. It is the statistical mean of the microscopic fluctuations of the kinetic energy of the systems' particles, and it is the source and the effect of the transfer of heat across a system boundary.

2.2.4 Geothermal gradient

2.2.4.1 Definition

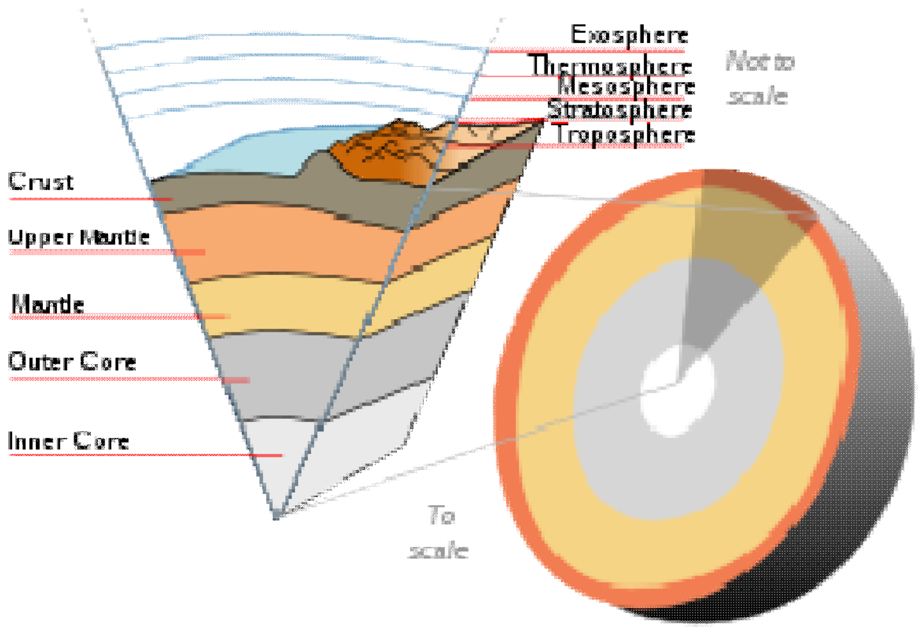

Fig 1.7.Earth cutaway from core to exosphere.(** *Source-google images* ***)

The **geothermal gradient** is the rate at which the Earth's temperature increases with depth, indicating heat flowing from the Earth's warm interior to its cooler surface. Away from tectonic plate boundaries, it is 25-30°C per km of depth in most of the world. The Earth's internal heat comes from a combination of residual heat from planetary accretion (about 20%) and heat produced through radioactive decay (80%). The major heat-producing isotopes in the Earth are potassium-40, uranium-238, uranium-235, and thorium-232. At the center of the planet, the temperature may be up to 7,000 K and the pressure could reach 360 GPa. [11]

2.2.4.2 Heat sources

Temperature within the Earth increases with depth. Highly viscous or partially molten rock at temperatures between 650 to 1,200 °C (1,202 to 2,192 °F) is postulated to exist everywhere beneath the Earth's surface at depths of 50 to 60 miles (80 to 100 kilometers), and the temperature at the Earth's center, nearly 4,000 miles (6,400 km) deep, is estimated to be 5650 ± 600 Kelvin. The heat content of the earth is 10^{31} joules. [11]

- Much of the heat is believed to be created by decay of naturally radioactive elements. An estimated 45 to 90 percent of the heat escaping from the Earth originates from radioactive decay of elements within the mantle.
- Heat of impact and compression released during the original formation of the Earth by accretion of in-falling meteorites.
- Heat released as abundant heavy metals (iron, nickel, copper) descended to the Earth's core.
- Some heat may be created by electromagnetic effects of the magnetic fields involved in Earth's magnetic field.
- 10 to 25% of the heat flowing to the surface may be produced by a sustained nuclear fission reaction in Earth's inner core, the "georeactor" hypothesis.
- Heat may be generated by tidal force on the Earth as it rotates; since land cannot flow like water it compresses and distorts, generating heat.

Table 1.0 Present-day major heat-producing isotopes [11]

Isotope	**Heat release [W/kg isotope]**	**Half-life [years]**	**Mean mantle concentration [kg isotope/kg mantle]**	**Heat release [W/kg mantle]**
^{238}U	9.46×10^{-5}	4.47×10^{9}	30.8×10^{-9}	2.91×10^{-12}
^{235}U	5.69×10^{-4}	7.04×10^{8}	0.22×10^{-9}	1.25×10^{-13}
^{232}Th	2.64×10^{-5}	1.40×10^{10}	124×10^{-9}	3.27×10^{-12}
^{40}K	2.92×10^{-5}	1.25×10^{9}	36.9×10^{-9}	1.08×10^{-12}

2.2.4.3 Heat flow

Heat flows constantly from its sources within the Earth to the surface. Total heat loss from the earth is 42 TW (4.2×10^{13} watts). This is approximately 1/10 watt/square meter on average, (about 1/10,000 of solar irradiation,) but is much more concentrated in areas where thermal energy is transported toward the crust by Mantle plumes; a form of convection consisting of upwellingôs of higher-temperature rock. These plumes can produce hotspots and flood basalts. The Earth's crust effectively acts as a thick insulating blanket which must be pierced by fluid conduits (of magma, water or other) in order to release the heat underneath. More of the heat in the Earth is lost through plate tectonics, by mantle upwelling associated with mid-ocean ridges. The final major mode of heat loss is by conduction through the lithosphere, the majority of which occurs in the oceans due to the crust there being much thinner than under the continents.

The heat of the earth is replenished by radioactive decay at a rate of 30 TW. The global geothermal flow rates are more than twice the rate of human energy consumption from all primary sources. [12]

The geothermal gradient has been used for space heating and bathing since ancient roman times, and more recently for generating electricity. About 10 GW of geothermal electric capacity is installed around the world as of 2007, generating 0.3% of global electricity demand. An additional 28 GW of direct geothermal heating capacity is installed for district heating, space heating, spas, industrial processes, desalination and agricultural applications. [11]

2.2.4.4 Variations

The geothermal gradient varies with location and is typically measured by determining the bottom open-hole temperature after borehole drilling. To achieve accuracy the drilling fluid needs time to reach the ambient temperature. This is not always achievable for practical reasons.

In stable tectonic areas in the tropics a temperature-depth plot will converge to the annual average surface temperature. However, in areas where deep permafrost developed during the Pleistocene a low temperature anomaly can be observed that persists down to several hundred metres. [13]

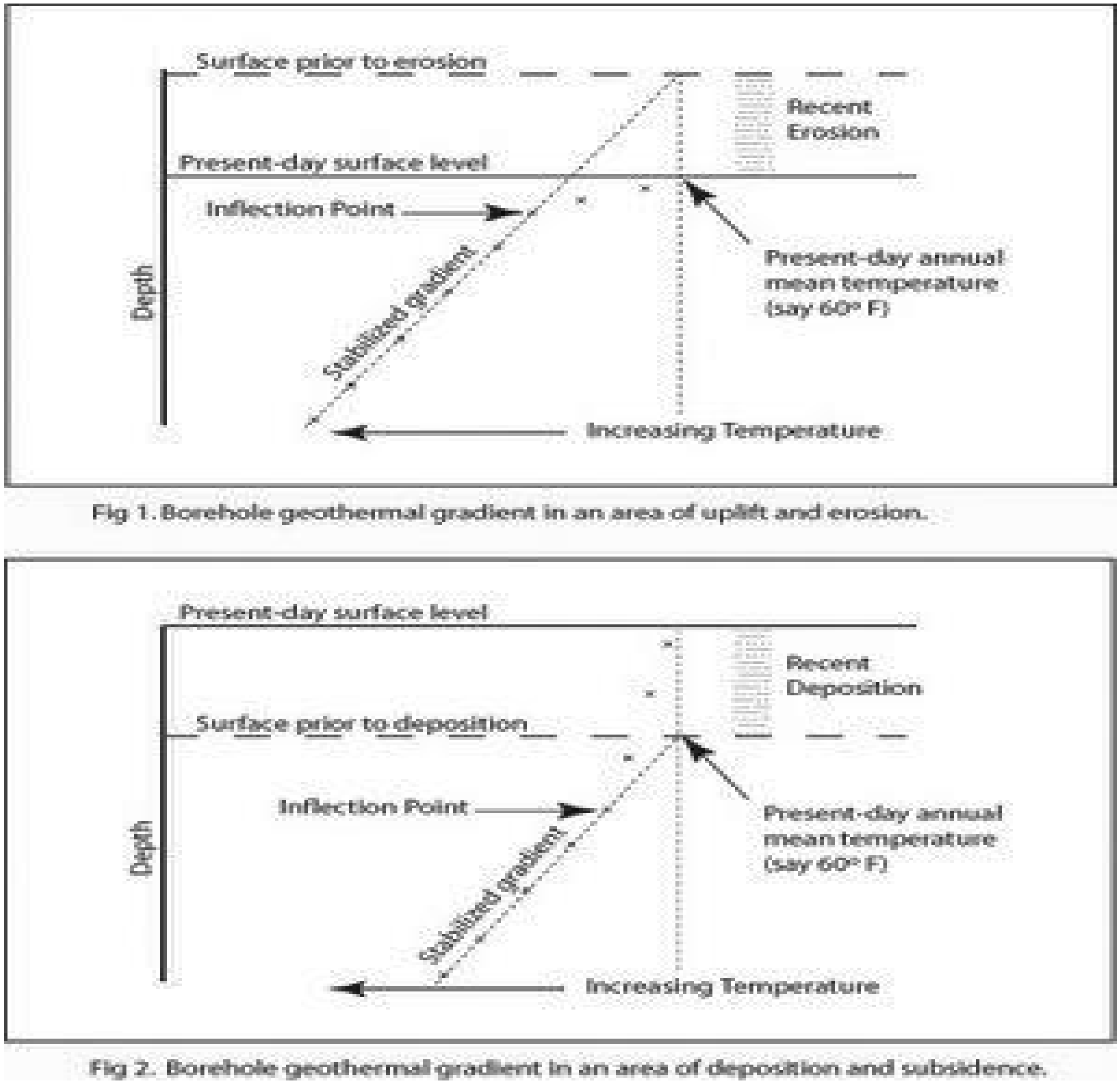

Fig 1. Borehole geothermal gradient in an area of uplift and erosion.

Fig 2. Borehole geothermal gradient in an area of deposition and subsidence.

Fig 1.8 geothermal gradients in areas of erosion and uplift (Source – Google images)

In areas of Holocene uplift and erosion as in the Fig 1.9 above the initial gradient will be higher than the average until it reaches an inflection point where it reaches the stabilized heat-flow regime. If the gradient of the stabilized regime is projected above the inflection point to its intersect with present-day annual average temperature, the height of this intersect above present-day surface level gives a measure of the extent of Holocene uplift and erosion. In areas of

Holocene subsidence and deposition (Fig 1.9 above) the initial gradient will be lower than the average until it reaches an inflection point where it joins the stabilized heat-flow regime.

In deep boreholes, the temperature of the rock below the inflection point generally increases with depth at rates of the order of 20 K/km or more. Fourier's law of heat flow applied to the Earth gives $q = Mg$ where q is the heat flux at a point on the Earth's surface, M the thermal conductivity of the rocks there, and g the measured geothermal gradient. A representative value for the thermal conductivity of granitic rocks is $M = 3.0$ W/mK. Hence, using the global average geothermal conducting gradient of 0.02 K/m we get that $q = 0.06$ W/m^2. This estimate, corroborated by thousands of observations of heat flow in boreholes all over the world, gives a global average of 6×10^{-2} W/m^2. Thus, if the geothermal heat flow rising through an acre of granite terrain could be efficiently captured, it would light four 60 watt light bulbs.

A variation in surface temperature induced by climate changes and the Milankovitch cycle can penetrate below the Earth's surface and produce an oscillation in the geothermal gradient with periods varying from daily to tens of thousands of years and an amplitude which decreases with depth and having a scale depth of several kilometers. Melt water from the polar ice caps flowing along ocean bottoms tends to maintain a constant geothermal gradient throughout the Earth's surface. [13]

If that rate of temperature change were constant, temperatures deep in the Earth would soon reach the point where all known rocks would melt. We know, however, that the Earth's mantle is solid because it transmits S-waves.

The temperature gradient dramatically decreases with depth for two reasons:

First, radioactive heat production is concentrated within the crust of the Earth, and particularly within the upper part of the crust, as concentrations of uranium, thorium, and potassium are highest there: these three elements are the main producers of radioactive heat within the Earth.

Second, the mechanism of thermal transport changes from conduction, as within the rigid tectonic plates, to convection, in the portion of Earth's mantle that convects. Despite its solidity, most of the Earth's mantle behaves over long time-scales as a fluid, and heat is transported by advection, or material transport. Thus, the geothermal gradient within the bulk of Earth's mantle is of the order of 0.3 Kelvin per kilometer, and is determined by the adiabatic gradient associated with mantle material (peridotite in the upper mantle).

This heating up can be both beneficial or detrimental in terms of engineering: Geothermal energy can be used as a means for generating electricity, by using the heat of the surrounding layers of rock underground to heat water and then routing the steam from this process through a turbine connected to a generator.

On the other hand, drill bits have to be cooled not only because of the friction created by the process of drilling itself but also because of the heat of the surrounding rock at great depth. Very deep mines, like some gold mines in South Africa, need the air inside to be cooled and circulated to allow miners to work at such great depth.

2.2.5 Plate tectonics

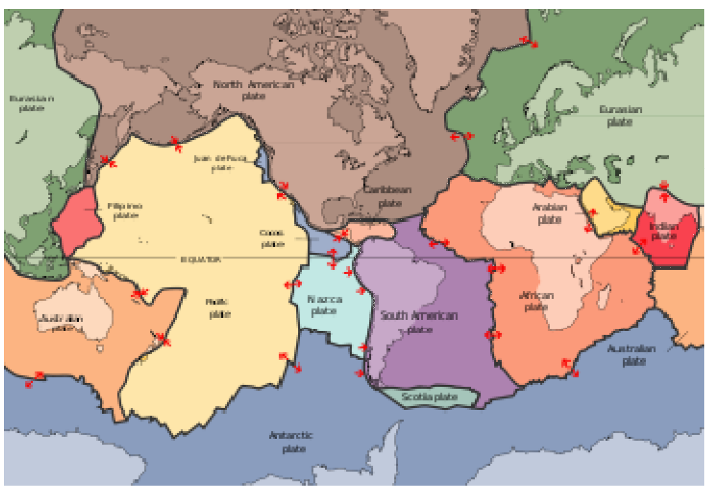

Fig 1.9 The tectonic plates of the world were mapped in the second half of the 20th century. (Source – Google images)

2.2.5.1 Definition

Plate tectonics is a scientific theory which describes the large scale motions of Earth's lithosphere. The theory builds on the older concepts of continental drift. The lithosphere is broken up into what are called "tectonic plates".

2.2.5.2 Key principles

The outer layers of the Earth are divided into lithosphere and asthenosphere.

The key principle of plate tectonics is that the lithosphere exists as separate and distinct *tectonic plates*, which ride on the fluid-like (visco-elastic solid) asthenosphere.

The location where two plates meet is called a *plate boundary*, and plate boundaries are commonly associated with geological events such as earthquakes and the creation of topographic features such as mountains, volcanoes, mid-ocean ridges, and oceanic trenches.

2.2.5.3 Types of plate boundaries

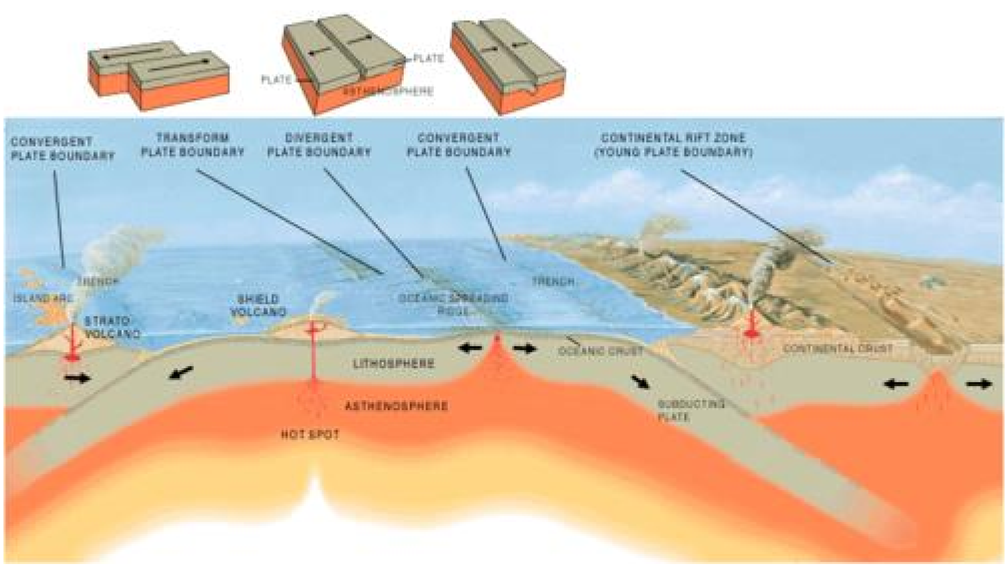

Fig 2.0 Three types of plate boundary. (Source – Google images)

The different types of plate boundaries are:

Transform boundaries (Conservative)

Divergent boundaries (Constructive)

*Convergent boundaries (D*estructive) (or active margins) [13]

2.3 Geothermal power plants

2.3.1 Definition

A geothermal power plant captures and uses the heat from the earth to drive one or more steam turbines that turn one or more synchronous generators which generate carbon free energy and pollution free power.

2.3.2 Types of geothermal power plants

Currently there are three technologies being used to generate geothermal power:

1. Dry steam technology
2. Flash steam technology
3. Binary cycle technology

2.3.2.1 Dry steam power plants

Dry steam power plants systems were the first type of geothermal power generation plants built. They use the steam from the geothermal reservoir as it comes from wells, and route it directly through turbine/generator units to produce electricity

Fig 2.1 Dry steam coming from the ground (Source – Renewable energy institute)

Steam plants use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. (Also eliminating the need to transport and store fuels!) This is the oldest type of geothermal power plant. It was first used at Lardarello in Italy in 1904, and is still very effective. Steam technology is used today at The Geysers in northern California, the world's largest single source of geothermal power. These plants emit only excess steam and very minor amounts of gases.

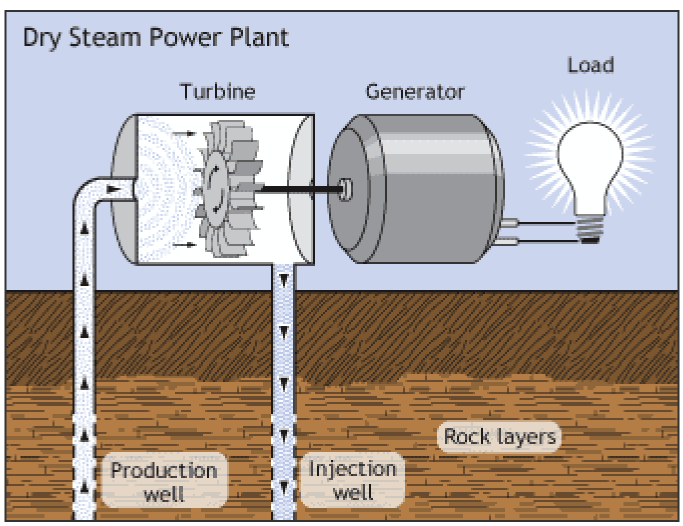

Fig 2.2 Dry steam power plant (Source – Renewable energy institute)

2.3.2.2 Flash steam power plants

Flash steam plants are the most common type of geothermal power generation plants in operation today. They use water at temperatures greater than 360°F (182°C) that is pumped under high pressure to the generation equipment at the surface

Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank to extract even more energy.

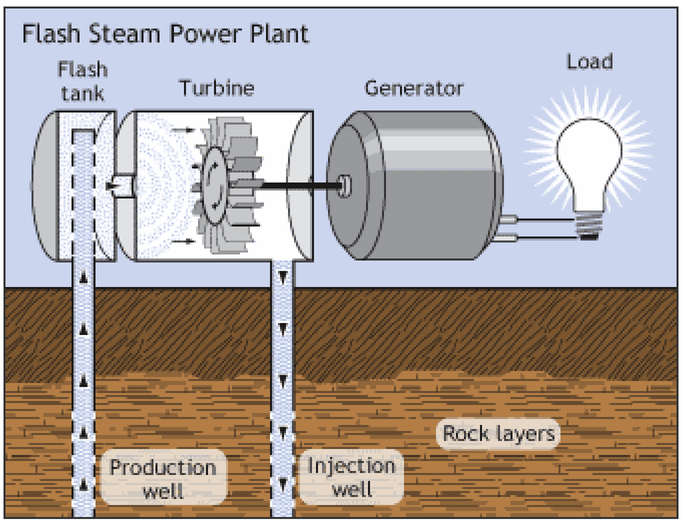

Fig 2.3 Flash steam power plant (Source – Renewable energy institute)

2.3.2.3 Binary cycle power plants

Binary cycle geothermal power generation plants differ from Dry Steam and Flash Steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units.

Most geothermal areas contain moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants. Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapor, which then drives the turbines. Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle plants.

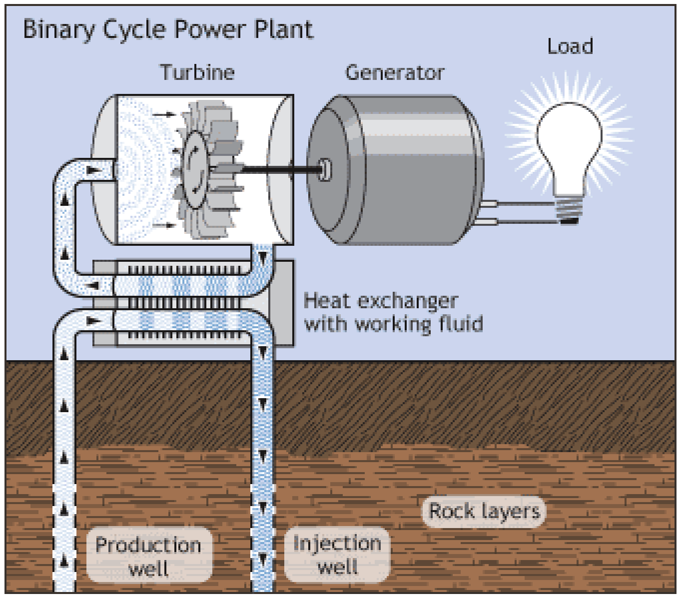

Fig 2.4 Binary cycle power plant (Source – Renewable energy institute)

2.3.3 Geothermal power exploration and drilling

2.3.3.1 Introduction

Prior to constructing a geothermal power plant and delivering power to the electrical grid a series of steps must be taken by a geothermal developer to ensure the successful completion of a geothermal development project. The first of these steps is conducting a thorough exploration program of any given geothermal resource site.

2.3.3.2 Exploration

2.3.3.2.1 Remote Sensing Technologies

Remote sensing is usually conducted by satellite or airborne observation which uses sensors to detect different wavelengths of light to differentiate between different rock types. The main advantage of conducting a remote sensing survey is that it can be done prior to initiating the expensive and lengthy procedure of obtaining the land rights to a resource. Thus remote sensing is an important ñfirst stepò in the exploration process.

Table 1.1 remote sensing technologies

Technology	**Advantages**	**Obstacles**
Satellite Imaging	Covers large area Less expensive	Reduced spatial and spectral resolution
Airborne ***Hyper spectral***	Higher spatial and spectral resolution	More expensive Covers smaller area
Light detection and ranging	Can penetrate dense vegetation Data layers are easy to integrate in a GIS	Processing data requires specific skills sets and software

2.3.3.2.2 Geochemical Technologies

Itôs initiated upon the obtaining of land rights. If conducted previously they are typically Continued after a developer gains access to the geothermal resource.
An important issue in developing geothermal resources is how to determine how hot the resource might be at depth without drilling.

The underlying assumption of geochemical analysis in geothermal exploration is that surface manifestations of geothermal fluids can provide information on temperature and physiological conditions in the subsurface geothermal reservoir. Obtaining this information is accomplished by using geothermometers that are based on the relative amounts and ratios of various elements or isotopes in the water. The levels of these elements within the geothermal fluid and with respect to each other provide insights into the geothermal reservoir temperature.

2.3.3.2.3 Geophysical Technologies

Geophysical techniques provide indications of the structure of subsurface geology and how those structures can be drilled to bring hot water from the geothermal aquifer to the surface. Combined with geochemical studies, geophysical analysis seeks to identify temperatures, permeability, and the orientation of fractures at depth effective in certain resource areas than others, guaranteeing their widespread use. Still, certain geophysical technologies are more widely used than others and incremental improvements in their technology or use could yield improved exploration success rates.

2.3.3.2.4 Seismic Imaging

Seismic-imaging surveys use explosive charges or man-made vibrations to direct waves into the subsurface at the location of a suspected geothermal resource. Waves that reflect off subsurface structural features are used to render a 3D image of the geothermal reservoir.

2.3.3.3 Drilling

Drilling at a geothermal prospect typically begins long before construction of the power plant is initiated. Thermal gradient holes (TGH) are usually drilled before drilling a deeper exploration hole (ñslim holeò), which are then followed by drilling a full-scale production well in order to glean more information about the temperature of a geothermal reservoir at depth.

2.3.3.3.1 Thermal Gradient Holes

The drilling of thermal gradient holes (TGH) is an important step prior to drilling a production well. The drilling of a TGH may even precede some geophysical surveys. TGHs are shallow and narrow, and can be drilled quickly using a truck-mounted rig. TGH measure the gradient ï i.e. the change in temperature vs. depth. A higher gradient indicates a greater temperature anomaly. The basic purpose of drilling a TGH is two fold. First, a TGH is designed to assess whether deeper temperatures in the geothermal reservoir will be hot enough to support commercial production. Second, a series of TGHs should also help to delineate a thermal anomaly and define the extent of the resource.

2.3.3.3.2 Core Drilling

Core drilling or ñslim-hole drillingò is a method of drilling in which a drill bit with a hollow center is used to extract cylinders, or ócoresô, of rock. Core drilling is sometimes used in the drilling of production wells as the well bore is drilled to greater depths. The cores that are recovered are analyzed in order to better understand subsurface geology and locate fractures within a particular resource. Coring bits are also sometimes used when drilling in loss of circulation zones.

2.3.3.3.3 Production Well Drilling

The drilling of production wells represents the transitional step from the exploration to the drilling and construction phase of developing a geothermal resource. However, this step is only complete once a production well is deemed successful

2.3.3.3.4 Injection Well Drilling

In order to complete the confirmation of a geothermal field, injection wells must be drilled in order to return hot water from the production zone back into the ground and into the geothermal aquifer.

2.3.3.3.5 Drilling bits

Costs associated with geothermal drilling are largely a function of depth which directly influences the time spent drilling. Due to the hard rock formations encountered in geothermal drilling, drilling contractors typically use rotary cone bits that grind and crush rock. The diamond PDC drill bit is commonly employed oil and gas operations with success and is viewed as inherently more efficient than rotary cone bits.

2.3.4 Effects of geothermal power production on environment

Fluids drawn from the deep earth carry a mixture of gases, notably ***carbon dioxide*** (CO_2), ***hydrogen sulfide*** (H_2S), ***methane*** (CH_4), and ***ammonia*** (NH_3). These pollutants contribute to global warming, acid rain, and noxious smells if released. Existing geothermal electric plants emit an average of 122 kg of CO_2 per megawatt-hour (MWh) of electricity, a small fraction of the emission intensity of conventional fossil fuel plants. plants that experience high levels of acids and volatile chemicals are usually equipped with emission-control systems to reduce the exhaust. Geothermal plants could theoretically inject these gases back into the earth, as a form of carbon capture and storage.

In addition to dissolved gases, hot water from geothermal sources may hold in solution trace amounts of toxic chemicals, such as ***mercury, arsenic, boron, antimony***, and salt. These chemicals come out of solution as the water cools, and can cause environmental damage if released. The modern practice of injecting geothermal fluids back into the Earth to stimulate production has the side benefit of reducing this environmental risk.

Plant construction can adversely affect land stability. Subsidence has occurred in the ***Wairakei field*** in New Zealand.

Enhanced geothermal systems can trigger earthquakes as part of hydraulic fracturing. [9]

2.3.5 Advantages and disadvantages of geothermal power

2.3.5.1 Advantages

Å Geothermal energy does not produce any pollution, and does not contribute to the greenhouse effect.

Å The power stations do not take up much room, so there is not much impact on the environment.

Å No fuel is needed.

Å Once you've built a geothermal power station, the energy is almost free.

It may need a little energy to run a pump, but this can be taken from the energy being generated.

2.3.5.2 Disadvantages

Å The big problem is that there are not many places where you can build a geothermal power station.

You need hot rocks of a suitable type, at a depth where we can drill down to them.

The type of rock above is also important, it must be of a type that we can easily drill through.

Å Sometimes a geothermal site may "run out of steam", perhaps for decades.

Å Hazardous gases and minerals may come up from underground, and can be difficult to safely dispose off.

2.3.6 Potential of geothermal power in the world

The International Geothermal Association (IGA) has reported that 10,715 megawatts (MW) of geothermal power in 24 countries is online, which was expected to generate 67,246 giga watts of electricity in 2010. This represents a 20% increase in geothermal power online capacity since 2005. IGA projects this will grow to 18,500 MW by 2015, due to the large number of projects presently under consideration, often in areas previously assumed to have little exploitable resource.

In 2010, the United States led the world in geothermal electricity production with 3,086 MW of installed capacity from 77 power plants; the largest group of geothermal power plants in the world is located at The Geysers, a geothermal field in California. The Philippines follows the US as the second highest producer of geothermal power in the world, with 1,904 MW of capacity online; geothermal power makes up approximately 18% of the country's electricity generation.

The largest group of geothermal power plants in the world is located at ***The Geysers***, a geothermal field in ***California, United States***. As of 2004, five countries (El Salvador, Kenya, the Philippines, Iceland, and Costa Rica) generate more than 15% of their electricity from geothermal sources.

.

Geothermal electricity is generated in the 24 countries listed in the table below. During 2005, contracts were placed for an additional 500 MW of electrical capacity in the United States, while there were also plants under construction in 11 other countries. Enhanced geothermal systems that are several kilometres in depth are operational in France and Germany and are being developed or evaluated in at least four other countries. [8]

Table 1.2 Installed geothermal electric capacity

Country	**Capacity (MW) 2007 [14]**	**Capacity (MW) 2010 [15]**	**percentage of national production**
USA	2687	3086	0.3%
Philippines	1969.7	1904	27%
Indonesia	992	1197	3.7%
Mexico	953	958	3%
Italy	810.5	843	
New Zealand	471.6	628	10%
Iceland	421.2	575	30%
Japan	535.2	536	0.1%
El Salvador	204.2	204	14%
Kenya	128.8	167	11.2%
Costa Rica	162.5	166	14%
Turkey	38	94	0.3%
Nicaragua	87.4	88	10%
Russia	79	82	
Papua-New Guinea	56	56	
Guatemala	53	52	
Portugal	23	29	
China	27.8	24	

France	14.7	16
Ethiopia	7.3	7.3
Germany	8.4	6.6
Austria	1.1	1.4
Australia	0.2	1.1
Thailand	0.3	0.3
TOTAL	**9,731.9**	**10,709.7**

2.4 Geothermal power production in Kenya

2.4.1 Introduction and brief history

Kenya is one of the few countries in the world engaging in serious exploitation of geothermal energy resources. Currently itôs ranked number 10 out of the 24 countries in the world which so far use geothermal energy. 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 1960ôs with surface exploration that culminated in two geothermal wells being drilled at Olkaria. In the early 1970ôs, 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. Additional wells were thereafter drilled to provide enough steam for the generation of electricity, and in June 1981 the first 15 MW generating unit ñOlkariaò was commissioned. This was the first geothermal power plant in Africa. The second 15 MW unit was commissioned in November 1982 and the third unit in March 1985, raising the total to 45 MW 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 MW with plans to generate a total of 64 MW in the next few years in the Olkaria West field (Mbuthi, 2005).By 2002 Kenya had so far exploited 127 MW of its total potential. (KPLC 2002).

2.4.2 Geothermal sites in Kenya

More than 14 high temperature potential sites occur along the Kenyan Rift Valley with an estimated potential of more than 7,000 MW. Other locations include: Homa Hills in Nyanza, Mwananyamala at the Coast and Nyambene Ridges. These prospects are at different stages of development.

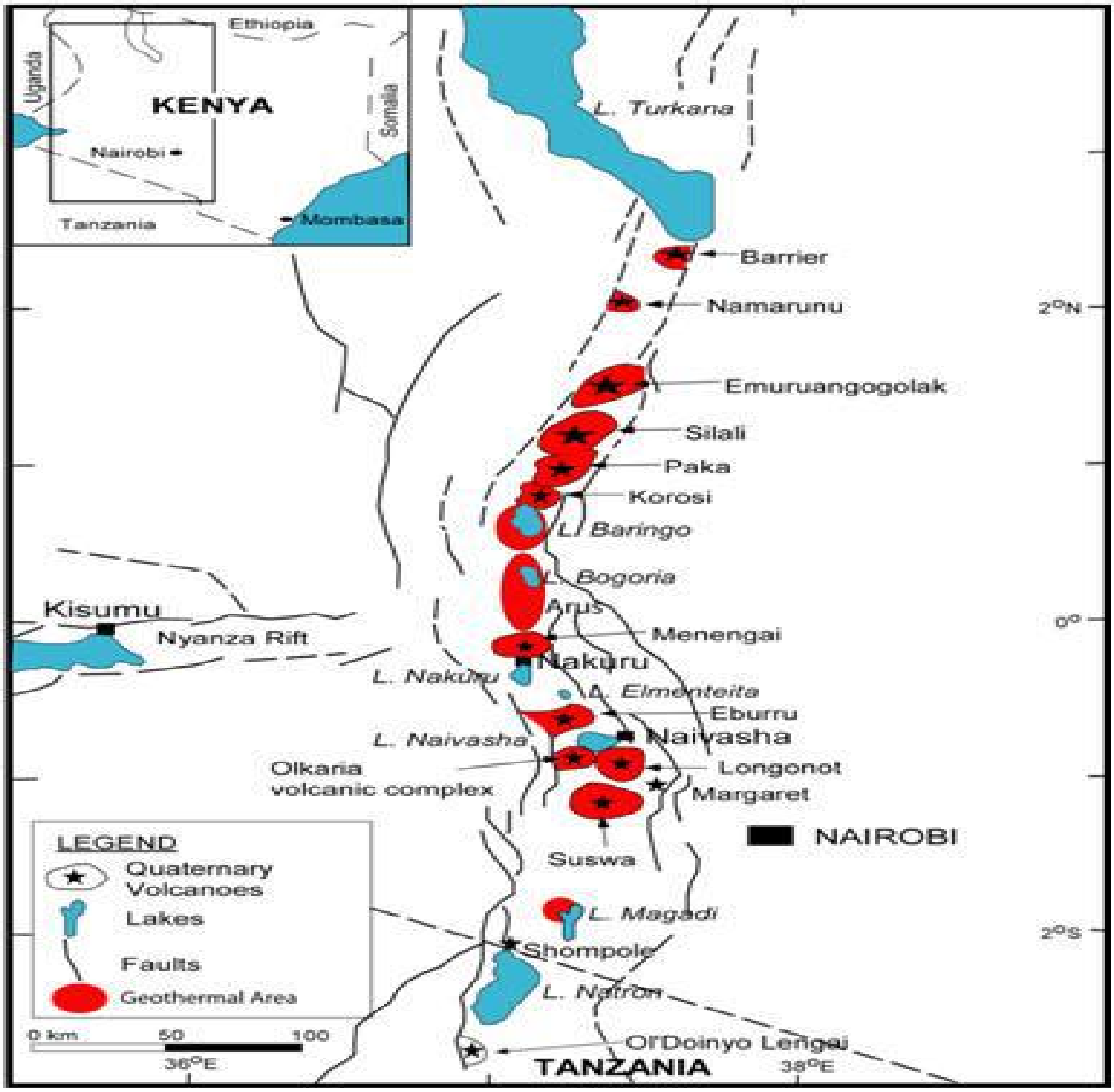

Fig 2.5 Geothermal sites in Kenya in the rift valley (Source – Geothermal Development

Company)

Geothermal Sites in Central Rift	Geothermal Sites in South Rift	Geothermal Sites in North Rift
1. Menengai	1. Olkaria	1. Lake Baringo
2. Eburru-Badlands	2. Longonot	2. Korosi
3. Arus-Bogoria	3. Suswa	3. Paka
	4. Lake Magadi	4. Silali
		5. Emuruangogolak
		6. Namarunu
		7. Barrier

(Data courtesy of Geothermal Development Company- Kenya)

2.4.3 Complete geothermal power plant sites.

2.4.3.1 Olkaria I Power Station

To date more than 33 wells have been drilled for ***Olkaria I*** power station. Thirty-one of these are currently connected to the power station while two of these have been retired. One well is currently being used for hot re-injection. The turbines are 4-stage single flow running with an inlet steam pressure of 5 bar absolute at a saturation temperature of 152^0 C and a steam consumption of 9.2 tonnes per hour for each megawatt hour produced. The plant has had an average availability and load factor of 98 per cent since commissioning. The plant has an installed capacity of 45 Mw. The power generated is connected to the national grid via a 132 kV transmission line.
Currently expansion is underway to increase its capacity by 70MW by 2013. ***(KENGEN, Horizon 1 projects)***

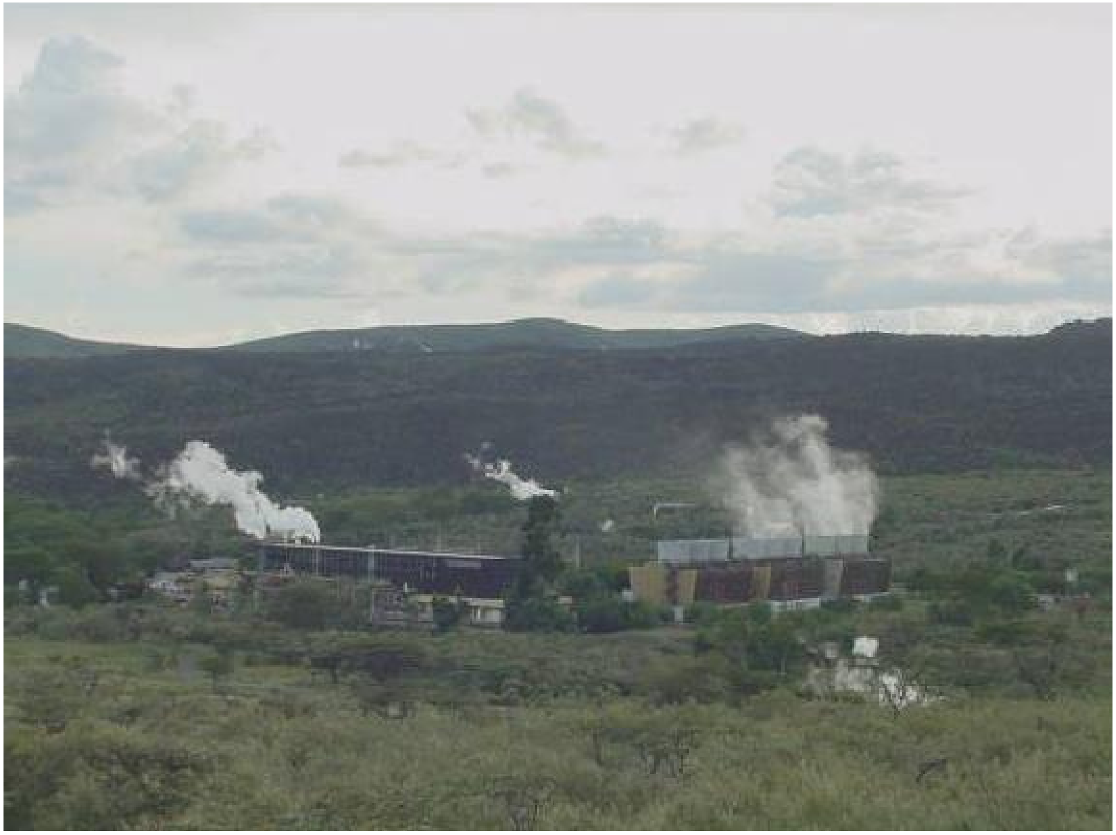

Fig 2.6 olkaria 1 power station

(Data courtesy of Geothermal Development Company- Kenya)

2.4.3.2 Olkaria II Power Station

Olkaria II Power Station is currently Africaôs largest Geothermal Power Station. It is currently generating about 105 MW and is the second geothermal plant that is operated by KenGen. The power plant was commissioned in November 2003.

The power station is located in the North Eastern Sector of the greater Olkaria geothermal field. Wells were drilled between 1986 and 1993 but construction of the power plant was delayed until the year 2000 when funds became available. The project was co-financed by the World Bank, the European Investment Bank, KfW of Germany and the Kenyan Government. Designed and constructed with an advantage of newer technology, this state-of-the-art plant is highly efficient in steam utilization.

Olkaria II Power Station operates on a single flash plant cycle with a steam consumption of 7.5 tonnes per hour per megawatt generated. The turbines are single flow six-stage condensing 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.

Fig 2.7 olkaria II power station

(Data courtesy of Geothermal Development Company- Kenya)

2.4.3.3 Olkaria III Power Plant

This is not only the first private geothermal power plant in Kenya, but also the first binary cycle plant in the country. Exploration Drilling of seven wells was completed in the Olkaria South West field, five wells were able to discharge with an output varying from 1 to 4 MW. The Kenya government put the Olkaria West field out for International bid in 1996. Two companies submitted responsive bids and, after evaluation, ORMAT International was awarded the right to develop Olkaria III to a capacity of 64 MW. In 1997, ORMAT International was licensed by the Kenya Government to generate 64 MW to 100 MW in the North West sector of the Olkaria resource now called the Olkaria III field. In August 2000, ORMAT commissioned 8 MW of geothermal generation that was later increased to 12 MW from a combined-cycle binary pilot plant. The plant is currently generating 48 MW and is earmarked for expansion which will see it produce 70 MW.

Fig 2.8 a close view of olkaria III power plant

(Data courtesy of Geothermal Development Company- Kenya)

2.4.3.4 Olkaria IV Power Plant

This is a newly commissioned power plant due for completion by 2013. Itôs estimated that after its completion it is going to have a capacity of 140 MW. ***(KENGEN, Horizon 1 projects)***

(Data courtesy of Geothermal Development Company- Kenya)

2.4.4 Kenya's energy profile

Kenya has a total installed electricity capacity (2008) of 1480MW of which 57% is supplied by hydropower with 290MW acting as an emergency capacity. Kenyaôs peak demand in 2008 averaged at 1,050MW. Other major energy sources include thermal (31.7%), geothermal (11%) and wind (0.3%). In 2007 the total primary energy supply was 18,305 ktoe with the countryôs total electricity consumption being 5,124 GW. Direct burning of wood and waste materials, plus some renewable-based power generation, was the dominant energy source for Kenya in 2009, accounting for an estimated 78% of primary energy demand (**PED**), followed by oil at 20% and hydro with a near 2% share of PED.

(Country energy profile: Kenya-(Courtesy of AFREPREN/FWD)

2.4.5 Government commitment to geothermal energy exploitation

Pressure is currently mounting for countries to exploit renewable energy resources. In Kenya the vast geothermal energy potential available is reason enough to stir enthusiasm to venture in its zone. However the up-front costs of doing the same are very large thus dissuading especially private investment in the sector. Looking at the alarming rates of persons living without electricity itôs imperative for the government to look into mechanisms of stimulating private sector participation in solving this problem.

In a bid to address this problem the government of Kenya has initiated mechanisms to encourage private companies to come in and invest in geothermal power production.

Government has embarked on the following:

- Reduction of exploration and drilling by having Geothermal Development Company do the drilling and exploration.
- Establishment of the National Energy Advisory Council charged with the responsibility of formulating concrete plans for expansion of energy resources over the next 20 years.
- Giving tax incentives at the rate of: 10 year tax reprieve for geothermal power plants of 50 MW, 7 year tax reprieve for geothermal power plants of 30 - 49 MW, and 5 year tax reprieve for geothermal power plants of 10 - 29 MW.
- Giving companies long term contracts with power purchasing agreement(PPA) on Built Own Operate Transfer(BOOT) agreement.
- Giving investment guarantees.

  (Sources- Energy Regulatory Commission: www.erc.co.ke, kengen: www.kengen.co.ke, Ministry of energy:

3 CHAPTER THREE: Discussion, Conclusion and Recommendations

3.1 Discussion

From the findings we can see that Kenya has vast geothermal resources mainly located on the rift valley. Over 20 sites have been explored of which around five are currently being exploited with an installed capacity of around 167 MW. The potential of geothermal energy of Kenya is currently rated at 7,000 MW owing to its location on the tectonic plates of the rift valley. Looking at Kenyaǒs energy profile we can see that geothermal energy is the third largest energy source currently at 11%.

From previous case studies on geothermal power potential in the country we can see that exploitation of geothermal power has been growing steadily. Some of the factors hampering its quick growth include:

Inadequate facilities and relevant expertise.

In conducive political climate which scares away investors and also influences negative or no government policies towards development of geothermal power.

Capital costs are so large hence individual /private investors cannot easily afford.

High risks involved.

Some of the mechanisms that can be employed to stimulate investment in geothermal power include:

Government giving incentives to potential investors to reduce overall capital costs.

Government to create a politically conducive environment for investment and formulate strong policies.

3.2 Conclusion

Kenya has a geothermal power potential of over 7,000 MW of which currently 167 MW has already been harnessed. Also, plants which will generate an extra 280MW by 2013 are being constructed. Kenya in vision 2030 envisions to have harnessed 5000 MW of geothermal energy. Therefore to aptly satisfy the energy demands of the Kenyan populace, stop importing power from other countries, and also be able to export power to other countries on a long term basis Kenya should invest seriously in geothermal power.

Looking at the current threats facing hydropower (depleting catchment areas) and the large expense of producing thermal power, it is safe to conclude that geothermal energy is the future of Kenyaŝs electricity solution.

3.3 Recommendation for further work

That a thorough investigation be done on the exact or near exact amount of power that can be derived from a specific size of explored land, with specific temperature, specific rocks/ isotopes available and specific rate of heat flow.

This would give a more exact value of the potential of geothermal power available in raw form.

4 References

1. World Energy Assessment (2001). Renewable energy technologies.

2. REN21 (2010). Renewables 2010 Global Status Report.

3. United Nations Environment Programme ñGlobal Trends in Sustainable Energy Investment 2007: Analysis of Trends and Issues in the Financing of Renewable Energy and Energy Efficiency in OECD and Developing Countriesò (PDF).

4. EWEA Executive summary "Analysis of Wind Energy in the EU-25" (PDF). European Wind Energy Association. http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WETF/Facts_Summary.pdf EWEA Executive summary.

5. Union of Concerned Scientists. How Biomass Energy Works

6. "Towards Sustainable Production and Use of Resources: Assessing Biofuels". United Nations Environment Programme. 2009-10-16. http://www.unep.fr/scp/rpanel/pdf/Assessing_Biofuels_Full_Report.pdf.

7. Duchane, Dave; Brown, Don (December 2002). "Hot Dry Rock (HDR) Geothermal Energy Research and Development at Fenton Hill, New Mexico". *Geo-Heat Centre Quarterly Bulletin* (Klamath Falls, Oregon: Oregon Institute of Technology). ISSN 0276-1084. http://geoheat.oit.edu/bulletin/bull23-4/art4.pdf.

8.GEA 2010,

9.Lund, John W. (June 2007), "Characteristics, Development and utilization of geothermal resources", *Geo-Heat Centre Quarterly Bulletin* (Klamath Falls, Oregon: Oregon Institute of Technology), ISSN 0276-1084, http://geoheat.oit.edu/bulletin/bull28-2/art1.pdf.

10. S. Blundell, K. Blundell (2006). ñConcepts in Thermal Physicsò. Oxford University Press. ISBN 0ï 19ï 856769ï 3.

11. Turcotte, D. L.; Schubert, G. (2002). "4". *Geodynamics* (2 ed.). Cambridge, England, UK: Cambridge University Press. ISBN 978-0-521-66624-4.

12. Rybach, Ladislaus (September 2007). "Geothermal Sustainability". *Geo-Heat Centre Quarterly Bulletin* (Klamath Falls, Oregon: Oregon Institute of Technology). ISSN 0276-1084. http://geoheat.oit.edu/bulletin/bull28-3/art2.pdf.

13.Stacey, Frank D. (1977). *Physics of the Earth* (2nd ed.). New York: John Wiley & Sons. ISBN 0-471-81956-5.

14.Bertani, Ruggero (September 2007), "World Geothermal Generation in 2007", *Geo-Heat Centre Quarterly Bulletin* (Klamath Falls, Oregon: Oregon Institute of Technology) 28 (3), ISSN 0276-1084, http://geoheat.oit.edu/bulletin/bull28-3/art3.pdf.

15. Holm, Alison (May 2010), *Geothermal Energy:International Market Update*, Geothermal Energy Association, pp. 7, http://www.geo-energy.org/pdf/reports/GEA_International_Market_Report_Final_May_2010.pdf.