Techno-Economic Assessment for Geothermal Energy in Zimbabwe

N. Chikwama
Department of Chemical and Process Systems Engineering, School of Engineering and Technology, Harare Institute of Technology, Zimbabwe
nodraxee@gmail.com
M. M. Manyuchi*
Department of Operations and Quality Management, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
*mercy.manyuchi@gmail.com

N. Sukdeo
Department of Operations and Quality Management, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
nsukdeo@uj.ac.za

Abstract

Geothermal energy has potential to be used as a clean renewable energy source to power the nation. This study evaluates the techno-economic assessment for setting up a 10-megawatt (MW) geothermal electricity based plant in Lubimbi, Zimbabwe. Neohexane was chosen as the conversion organic fluid of geothermal brine to geothermal electricity at 73 °C. A total investment of approximately USD 40 million is required to establish the 10 MW plant with a plant life of 30 years. An off-taker tariff of USD 0.14/kwh against a leveled cost of production of USD0.08 was proposed. A rate of return of 3.2% and a payback period of 7 years was achieved. The proposed development will contribute 0.5% to the energy requirements in the country.

Keywords: Electricity generation, geothermal energy, levelized cost of energy, techno-economic assessment

1. Introduction

Previous studies have estimated that geothermal energy production will reach 140 GW (gigawatts) by the year 2050 (Bertani, 2009). In Africa, countries like Kenya and Ethiopia have already started tapping geothermal electricity with both countries generating 29 MW (megawatts) and 7 MW respectively (Bertani, 2007). Geothermal energy can be used for directly heating individual buildings and to heat multiple buildings with various options shown in Figure 1.

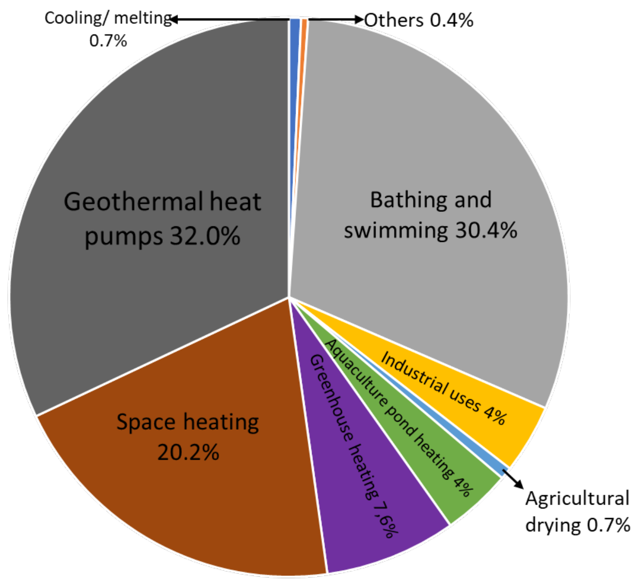

Figure 1: Applications of geothermal energy worldwide (Lund et al., 2005)

Currently Zimbabwe's main energy source is coal and has an energy deficit of around 2000MW at the same time, the usage of coal results in carbon dioxide emissions that causes climate change. The need to use alternatives like geothermal energy then becomes imperative. Geothermal energy derives from inside the earth whereby electrical power is generated from the fluid circulation at high temperature ranges 200-320 ◦C (Barbier, 2002; (DiPippo, 2015). These high temperatures result in the heat being brought to the surface through circulation of the groundwater and depths of 1200-1300 meters (; Mungwena, 2002; Chipfupi et al., 2018)). Heat energy can be tapped from the power plant through drilling of wells and energy values of more than 100 million gigawatt hours can be tapped (Shere, 2013., Zalangera et al., 2014). Geothermal systems are made up of mainly four components that are a heat source, reservoir, the fluid and a recharge area and are found in shale, limestone and granite rock types (Fridleifsson and Ragnarsson, 2007., Sigfusson and Uihlein, 2015., Schwerhoff and Sy, 2017). This study therefore aims to do research on a techno-economic valuation for the design of a 10 MW geothermal energy plant, which is set to be the future in energy and a vibrant economy.

2. Materials and Methods

2.1 Determination of vapor pressure of the secondary fluid

The chosen fluid for vapor pressure determination was neohexane (2.2 di methyl butane) which has a boiling point of 49.9 °C. This experiment is critical for determining the amount of vapor pressure produced by the neohexane if heated with the geothermal fluid at 73 ◦C. This temperature was chosen since the area of study chosen is Lubumbi thermal springs in Matabeleland North, Zimbabwe that have an unchanging temperature of 73 °C. An environment like that at the geothermal reservoir was simulated by using a water bath at constant temperature of 73 °C.

2.2 Determination of elements in geothermal brine

The objective of this test was to determine the elements in the geothermal brine so that design features of the equipment can withstand the oxidizations and scaling can be avoided in the pipes and mostly heat exchangers. The list of materials required included liter beakers, 20-mL syringe, two beakers, hot plate, and filter paper, funnel, pulverize, X-ray Fluorescence machine and geothermal brine from the geothermal reservoir.

2.3 Determination of plant capacity for electricity generation from geothermal energy

The capacity of the plant can be estimated using the following equation, which is called the Reserve Estimation Method as, indicated in Equation 1.

$$E = V\,C_v(T-T_o) * R/F/L \qquad (1)$$

Where: V=volume of the geothermal reservoir, C_V = volumetric specific heat of the geothermal reservoir, T = average temperature of the geothermal reservoir, T_o = rejection temperature, R = overall energy recovery efficiency, F = power plant capacity factor and L = power plant lifespan. The parameter R can be determined as indicated in Equation 2.

$$R = \frac{WeCv}{} / C_f \cdot (T - T_o) \qquad (2)$$

Where: R=recovery factor, C_f = specific heat of the geothermal reservoir fluid, W= maximum available thermodynamic work from the produced geothermal fluid, e = utilization factor to that accounts for mechanical and other losses that occur in a real power cycle.
The parameter C_V is given by Equation 3:

$$C_V = \rho_r C_r (1-\varphi) + \rho_f C_f \varphi \qquad (3)$$

Where ρ_r = density of rock matrix, C_r = specific heat of rock matrix, ρ_f = density of reservoir fluid and φ = reservoir porosity.
The parameter W is derived from the First and Second Laws of Thermodynamics as indicated in Equation 4:

$$dW = dq/ (1-T_o/T) \text{ and } dq = C_f /Dt \qquad (4)$$

Where: q represents thermal energy and T represents absolute temperature as indicated in Equation 5.

$$Q = \dot{m} C \Delta T \qquad (5)$$

Where: $\dot{m}$=mass flow rate of the geothermal reservoir, C =specific heat capacity of the geothermal fluid and ΔT=temperature difference between injection point and rejection point.

3. Experimental Results and Analyses

This section focused on the results of the experiments stated in section 2 and their analyses. The results will form the basis of the process design and working parameters of the geothermal energy 10 MW power plant.

3.1 Vapor pressure determination for pressure built up to basis to the design of the geothermal plant

The following results in Table 1 correspond to the organic fluid vapor pressure determination test. The vapor pressure of the neohexane increased with an exponential function $y=140.78e^{0.034X}$ with increase in the temperature as indicated in Figure 2.

Table 1: Behavior of neohexane to increase in temperature

Temperature (℃)	Pressure (mmHg)	Pressure (KPa)
31.18	402.44	53.65
37.27	500.71	66.76
43.89	627.95	83.72
48.88	732.09	97.60
49.08	744.07	99.20
49.54	755.26	100.69
50.07	768.00	102.39
50.53	779.38	103.91
54.65	896.91	119.58
58.35	1016.77	135.56
64.23	1241.43	165.51
66.75	1351.73	180.22

From Figure 2, as the temperature of the water bath was held constant the temperature of neohexane increased this was due to heat transfer between the two fluids. As temperature increased, more energy was given to the neohexane particles according to Brownian Motion, which resulted in vaporizing of the fluid and pressure, built up in the vessel, the pressure increased with increase in temperature. The experiment showed evidence that reasonable heat exchange between the two fluids can result in pressure built up which gives a basis to the design of the geothermal plant. At 66 °C from the experiments, the liquid had completely vaporized because it was in limited supply but since in the actual plant there will be a continuous supply of the fluid hence an extrapolation of the pressure at 73 °C (Figure 2) was made using the equation of the graph produced. The experiment took 58.5 seconds to vaporize completely the liquid.

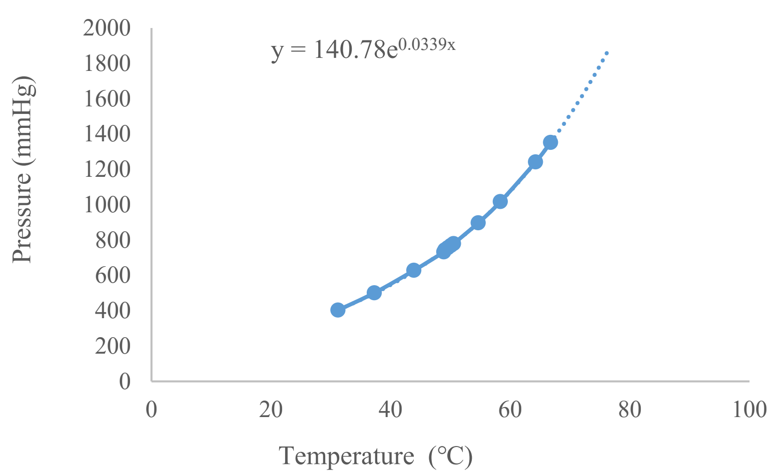

Figure 2: Effect of pressure and temperature on the geothermal water vapor temperature

3.2 X-Ray Fluorescence analysis for geothermal brine components

solid sample was analyzed and the results were as shown in Table 2. The highest composition in the geothermal water was from silicon (28ppm), aluminum (23ppm) and iron (23 ppm). Zotov et al. (2002) also indicated that the handling of wastewater from geothermal power plants could be difficult because of its silica scaling potential as the geothermal water-cools down.

Table 2: XRF results on element analysis of the geothermal water

Element	Composition (%)
Aluminium	23.06-23.09
Calcium	15.95-16.34
Chloride	17.89-18.08
Magnesium	15.17-15.23
Silicon	28.46-28.65
Sulphur	12.48-12.68
Iron	22.13-23.62

The XRF is limited to light elements from period three going up; this is because when an X-ray is fired to the elements they tend to behave like other elements, which makes it difficult to calculate the percentage amount available. For each element found in the sample, a standard was analyzed to see the deviation of the instrument when measuring. Since the target elements were silica, carbonates and sulphates, only the individual elements were analyzed. The molecular weight percentage in sample as shown in Table 3.

Table 3: Percentage composition of target compounds in geothermal water

Element	Molecule	%Element in sample
Aluminium	Al_2O_2	1.09-1.79
Calcium	$CaCO_3$	5.34-11.86
Silicon	SiO_2	15.34-33.35
Sulphur	SO_4	25.22-76.43
Iron	Fe_2O_3	0.46-0.66

As shown in Table 3, there is significant amount of compounds that result in scaling and stressing of equipment. Huang and Tian (2006) indicated that after used geothermal wastewater discharged into nearby pool and lowland, the underground water body and soil were found to be polluted. The experiments have shown us that brine at the reservoir temperature can be used to vaporize neohexane which has a boiling point of 49.9 ◦C and pressure was generated which in sufficient amount can be used to run a turbine.

4. Process Design

This section addressed significant contemplations for outline and choice of process procedures in the design of a geothermal power plant and its capacity. Also in this section are material and energy balances for the process.

4.1 Design basis

The design of geothermal power plants is uniquely different from the design of conventional power plants. Many factors come into play like temperatures and flow rates at the thermal reservoir, frequency and stability of temperatures. Composition of the fluid also comes into play as it as adverse effects on the equipment used.

4.1.1 Characteristics of Lubumbi thermal spring in Matabeleland North, Zimbabwe

Geothermal brine flow rate = 45 500-91 000 gallons/hour = 172-344m^3 /hour
Annual average temperature = 73 °C.

4.1.2 Geothermal brine characteristics

The key characteristics of the geothermal brine are its composition. Elements found in geothermal brine can result in adverse effects on the equipment hence it has to be characterized and mitigation measures put in place. Section 3 looked at these characteristics and it was concluded the water is highly scaling.

4.1.3 Product specification
The product of the 10 MW plant to be designed is geothermal electricity, which is at 50Hz. This electricity is the same frequency as the electricity being produced by conventional plants on the national grid.

4.2 Process Description
The geothermal fluid flows in a closed loop from the production well to the reinjection well as shown in Figure 3. The brine passes through heat exchangers where it loses its heat energy to the secondary fluid; these fluids do not interact directly. The secondary fluid gains energy, which increases its kinetic energy in accordance to the Brownian Motion Theory.

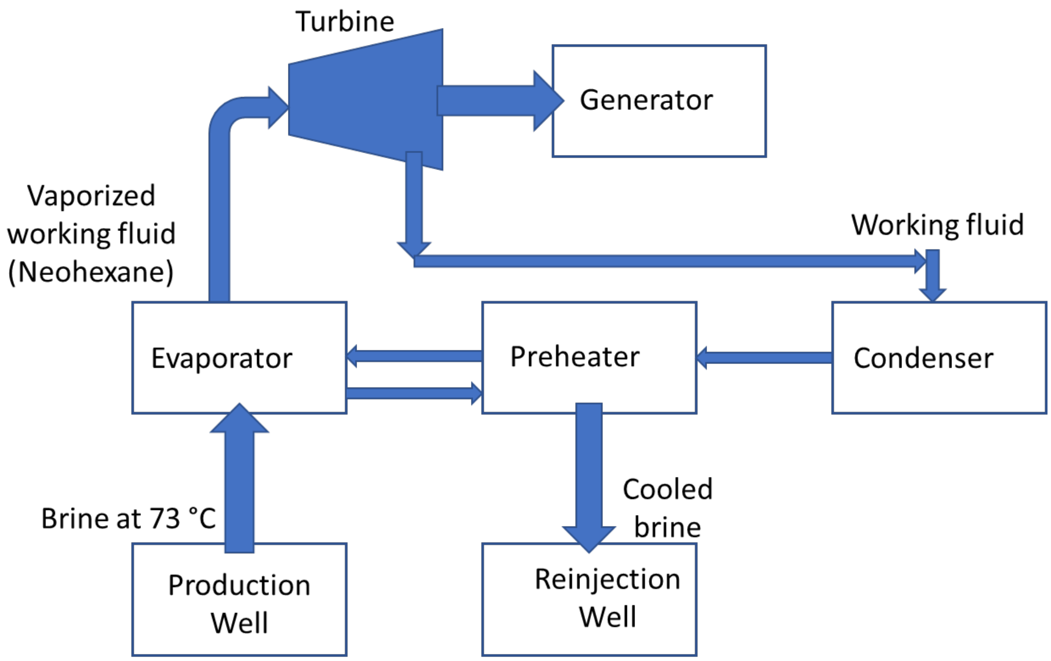

Figure 3: Schematic process flow diagram for binary geothermal power plant

4.3 Material and energy balances
The material and energy balances were deduced using the experimental data. The standard adiabatic models for components in Figure 3 were also used through application of the first law and second law of thermodynamics. Fouling in the heat exchangers and the pressure drops were assumed to be negligible. The geothermal brine was modelled to have a Cp for water at a temperature of 20 ◦C and 1 bar. According to the law of conservation of mass:
Material out = Material in + Generation -Consumption -Accumulation

At steady state, the material and thermodynamic balances for any control volume are represented in Equation 6 and 7:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (6)$$
$$\dot{Q} + \dot{W} = \sum \dot{m}_{out} h_{out} - \sum \dot{m}_{in} h_{in} \quad (7)$$

Where: *in* =represent the inlet state, *out* =represent the outlet state, $\dot{Q}$ =the net heat, $\dot{W}$ =work inputs, $\dot{m}$ = mass flow and h= enthalpy [kJ/kg].

4.4 Mass balance of geothermal fluid loop
For all the heat exchangers in the geothermal fluid loop the assumptions were:

Natural flow is 173 cubic meters /hr. = 173 000 kg/hr.
But using a pump like in other geothermal system the flow can be adjusted to mass in =76.29 kg/s
Whereby: Generation = 0, Accumulation = 0. Hence mass out =76.29 kg/s.
Hence, the mass from production well and mass at reinjection well is the same. A summary of the mass balances on the geothermal loop is shown in Table 4.

Table 4: Mass balance on geothermal loop

Equipment	Mass $_{in}$	Mass $_{out}$
Evaporator	76.29 kg/s.	76.29 kg/s.
Pre heater	32.72 kg/s.	32.72 kg/s.

4.5 Energy balances on geothermal loop

Equation 8 represents the energy balances on the geothermal loop.

$$Q = \dot{m}C\ \Delta T \qquad (8)$$

The principle for the energy conservation was used on the working fluid to the evaporator as represented by Equation 9 and 10.

$$q = q_A + q_B = m_R\ [C_{P,R}\ (T_{sat} - T_{C,i}\ ) + h_{fg}\ ] \qquad (9)$$

$$= m_R\ [2200.85\text{J/kg.K}\ (66°C - 31°C\ ) + 3.05 * 10^5\text{j/kg}] \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Computing the Q thermal of the system assuming ambient temperature at reinjection well
Mass flow is 173 m^3/hr =274,629.60 kg/hr.= 76.29*kg/s

$$T_{h,o} = T_{h,i} - \frac{q}{m_G\ Cp,g} = 73°C - \frac{q}{76{,}29\text{kg/s} * 4267\text{j/kgK}} \qquad (11)$$

$$25°C = 73°C - \frac{q}{76{,}29\text{kg/s} * 4267\text{j/kgK}} \qquad (12)$$

Hence q =76.29*4267*(346.15-298.15) =15,624,528 J/s =15625 Kw (13)

Assuming 80% thermal transfer of the heat exchanger system, Q is represented by Equation 14.

$$Q_{\text{working fluid}} = 15625*0.8 = 12500\text{Kw} \qquad (14)$$

Substituting $Q_{\text{working fluid}}$ in to Equation (11)

$$Q_{\text{working fluid}} = 15625*0.8 = 12500\ \text{Kw} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

$$= m_R\ [2200.85\text{J/kg.K}\ (66°C - 25°C\ ) + 3.05 * 10^5\text{j/kg}] \ldots\ldots\ldots (16)$$

$$12500\text{kW} = m_R\ [2200.85\text{J/kg.K}\ (66°C - 31°C) + 3.05 * 10^5\text{j/kg}] \ldots (17)$$

$$12500\text{kW} = m_R\ 382029.75\text{J/kg} \qquad (18)$$

$$m_R = \frac{12500000\text{J/s}}{382029.75\text{J/kg}} = 32.72\text{kg/s} \qquad (19)$$

Table 5: Overall mass balance and energy balance on heat exchanger system

Type of fluid	Q $_{thermal}$	Mass $_{in}$	Mass $_{out}$
Geothermal brine	15625 Kw	76.29 kg/s	76.29 kg/s
Working fluid (Neohexane)	12500 Kw	32.72 kg/s	32.72 kg/s

4.6 Work done by turbine

Work done by the turbine is represented by Equation 20.

$W_{turbine} = m_{wf}(\Delta h)\eta_f$…………………………………… ……………(20)

Where: h_1 = Enthalpy of organic fluid at turbine outlet (kJ/kg), h_2 = Enthalpy of organic fluid at turbine outlet assuming isentropic expansion (kJ/kg) and η_f = Efficiency of the turbine.
But:

$\eta_f = \frac{work\ done\ by\ turbine}{Q\ heat\ exchanger}$……………………………………………………(21)
Assuming a turbine efficiency of 80%
$80\% = \frac{work\ done\ by\ turbine}{12500kw}$…………………………………… ………(22)
0.8 *12,500,000w=work done by turbine which =10,000,000W

Hence enthalpy change in turbine is:
$W_{turbine} = m_{wf}(\Delta h)\eta f$ (23)
$\frac{\text{Wturbine}}{\text{mass } flow\ of\ fluid} = \Delta h = \frac{\text{10000kj/s}}{\text{32.720kg/s}} = 305.63$ kj/kg………………… (24)

4.7 Mass and energy balance for air
Mass air in =mass air out=mass air capacity of machine
Mass air capacity of the machine was provided by the original equipment manufacturer (OEM). This organization makes devices from component parts bought from other organizations.
as per energy requirements

5. Site Selection and plant layout
This section focused on issues to do with site location for the 10 MW geothermal power plant. Geothermal power plants are site specific and hence there is need to consider all factors to have a functional plant.

5.1 Site selection
Any on grid electrical power plant is composed of the following a fuel source, process plant, a substation and an electrical grid. When the issue falls, down to geothermal power plants, the plant now composes of the thermal wells, which pose as the fuel source, the plant in this case which runs on an organic Rankin Cycle and the sub-station since it is going to be an on grid power plant. The following factors were considered: nearness to geothermal well, proximity to the national electrical grid, distance from residential areas, availability of land, cultural and religious issues and prospects of future land use by Government. Research helped identify the hot springs in Lubumbi area, which are located north of the Shangani River bank in Matabeleland North, Zimbabwe. The well heat flow measurements in Lubumbi indicated the heat flow profile around 73 ◦C, which was used in experiments and design of the technology to harness the energy. Logically the best site would be exactly on the site of the geothermal wells.

5.2 Geothermal source and proximity to residential area
The geothermal source is the Lubimbi hot springs in Matabeleland North, Zimbabwe. Within the vicinity of the hot springs, there is a school and residential area. South of the hot springs about three miles away, there is the Shangani River. Hence, we there are three alternatives for the plant North East and South East of the hot springs area. Both sites are equally distant from the hot springs.

5.3 Land use
An entire geothermal field utilizes 4000-33000 m^2 per megawatt (MW) versus 20000-40000 m^2 per MW for nuclear operations and 80 000 m^2 per MW for coal power plants (Benito et al., 2005). Coal power plants also require huge acreages for mining their fuel. Hence, this plant will require about 80 000 m^2 per MW since binary power plants have low land use. Geothermal plants have low emissions and hence they pose no harm to the people who inhabit the area, though the reinjection well may pose a threat to aquatic life, as the water is high of sulphur content. Hence southeast of the hot springs may not be the best choice if that factor is put into consideration.

5.4 National grid, substations and future government prospects for land use
For Independent power producers to enjoy investment returns there is need to be close to the national Grids in order to be able to sell to the grid. The accessible grid line is the Hwange substation in Matabeleland North, Zimbabwe. The construction cost of connecting to the grid is much cheaper using the north east of the hot springs since the

distance is shorter and it gives access to a grid path which has already been cleared that connects Hwange and Sherwood.

5.5 Description of chosen site

The factors discussed in the previous section show that area North West of the hot springs is the best location. The chosen site is shown in Figure 4.

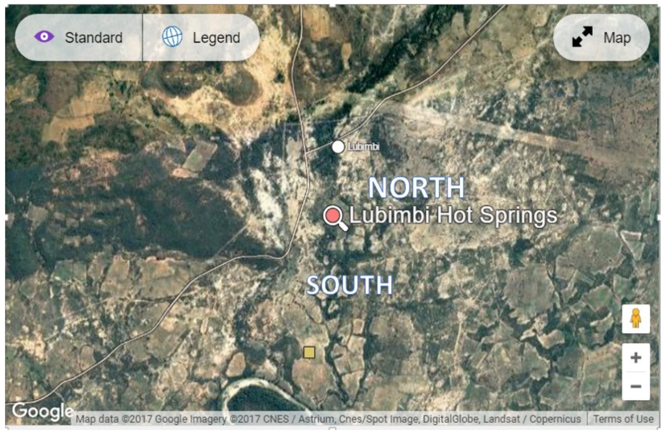

Figure 4: Lubumbi hot springs location in Matabeleland North, Zimbabwe

5.5.1 Environmental and legal considerations

The area is communal land its use is governed by the Communal Land Act 20:04 hence by law it can be used. Legally to use the land we would need to approach the local chiefs and council to abide to both the government legislation and still maintain a local cultural integrity.

5.5.2 Technical

This area is technically feasible since it is near the geothermal well for potential energy generation.

5.5.3 Economical

In the geothermal niche, the site selection has to be economical. Though the land is virgin, it is also near the national grid, which makes selling the electricity to the Zimbabwe Electricity Supply Authority (ZESA) as the off taker, which makes the risk worth the take.

5.6 Site layout

Geographical arrangement of buildings and plant area (equipment) has to be done in a manner, which makes process flow economical and values ergonomics as the plant workers need to be able to carry out their work efficiently. Figure 4 shows the area that relate the site location to the set layout considering all factors that have been discussed in this section.

6. Environmental Impact Assessment

The Environmental Impact Assessment (EIA) was prepared as required by the regulations of Zimbabwe. This was to insure environmentally friendly activities, which are not only limited to production well operation and drilling. There are also changes in the neohexane vapor and the geothermal brine cooling system from water to air, which is more environmentally friendly and constructions and operations of internal electricity transmission from plant to the grid and these must be accounted for.

6.1 Environmental Legislative Requirements

Implementation of this project will not only bring positive impacts but also possibilities of negative impacts on physical-chemical components, biological, socio-economic, socio-cultural and public health components. During the processes of geothermal energy development and utilization, the negative impact on surrounding environment will be caused through the generation of wastewater, waste gas and waste heat of geothermal water. Geothermal energy after uses can cause environmental pollution including the water pollution, air pollution, thermal pollution. These constitute a hazard to water, air, soil and crops (Huang and Tian., 2006). The negative environmental impact can be caused by super-exploitation was underestimated before exploitation of geothermal field, so, in the early stage of development in several geothermal fields the pressure of geothermal reservoir decreased and resources dried up leading the subsidence, deformation and other environmental issues (Huang and Tian., 2006). Geological hazards such as landslides and slope failure hazards may occur in several locations of hydrothermal alteration zones in the high-temperature geothermal active areas.

Following protocol, this section was prepared in accordance to the Environmental Management Agency and the Environment Management Act (Chapter 20:27). The Act provides for the sustainable management of natural resources and protection of the environment; the prevention of pollution and environmental degradation.

6.2 Background of Lubumbi geothermal field

Lubumbi hot springs in Matabeleland North in Zimbabwe under communal land, which has not developed much, but since the mining of coal in nearby areas, there has been some development in infrastructure and the town itself. The development of Lubumbi geothermal field and the construction of a 10 MW geothermal power plant are located in the Matabeleland area of Zimbabwe, in the communal lands of Lubumbi.

7. Economic Analysis

Geothermal power production costs analysis is mainly divided in amortization of the initial capital investment, power production operation and maintenance costs (Hance, 2005). The economic feasibility of harnessing energy from the Lubimbi hot springs was based on a levelised cost of electricity model (LCOE). The LCOE financial model considers all financial factors for a geothermal plant consideration (Hance, 2005).

7.1 Bill of quantities

The bill of quantities (BOQ) is a methodical way of recording all materials required in a project and for tendering purposes (Ashworth and Hogg., 2007). The BOQ for the geothermal energy plant is given in Table 6.

Table 6: Bill for geothermal power plant and wells

Well field and Drilling Cost	USD
Confirmation well drilling cost	5,000,000
Production well drilling cost	10,500,000
Injection well drilling cost	7,000,000
Surface equipment cost	125,000
Well stimulation	1,000,000
Fracturing for EGS cases	375,000
Production pump cost	700,000
Non-well costs	250,000
Power plant	**USD**
Heat exchangers	250,000
Condensers	400,000
Pump costs	160,000
Turbine generator	3,000,000
Cooling tower (flash plants)	350,000
NCG removal system (flash plants)	12,500
Flash vessels (flash plants)	125,000
H_2S removal system	50,000
Interconnection	**USD**
Substation	500,000
Transformer	250,000
Metering	75,000
Reserves and financing costs	**USD**
Lender fee	451,838
Interest during construction	3,162,863
Other equity and debt closing costs	**USD**
Initial funding of debt service and working capital/O and M reserves	3,388,950
Total installed cost	7,003,650

7.2 Capital investment

Capital investment involves the purchase of items such as land, machinery, buildings and equipment. The proposed capital investment is presented in Table 7.

Table 7: Total project cost

Cost Category	USD
Well field and drilling	24,950,000
Power plant	4,347,500
Interconnection	825,000
Reserves and financing costs	7,003,650
Total installed cost	**37,126,150**

7.3 Levelized cost of electricity

The levelised cost of electricity (LCOE) model calculations affixes all cost factors with the possible energy elements to estimate a unit cost of electricity. This calculation is used in most energy manufacturing technologies. The LCOE is the final calculation within the model sequence and is expressed as represented by Equation 25 (Astolfi et al., 2010). The levelized cost of electricity is given in Table 8.

$$LCOE = TC / TE \quad (25)$$

Where: TC is the total cost and TE is the total energy

Table 8: Levelized cost for the geothermal energy plant

Geothermal plant requirements		
	Capacity	10 MW
	Unit	
Capital cost (EPC)	USD/kW	3600
Land cost	%	2%
Allowance for funds under construction	%	7%
T_X/Dx integration cost	%	3%
Fixed O and M costs	USD/kW/yr	9%
Variable O and M costs	USD/kWh	0%
Fuel costs	USD/kWh	
Plant lead time	years	1%
Capacity factor	%	95%
LCOE	USD/kWh	8%
General Assumptions		
Economic life (generation)	30	years
WACC Calculation		
Debt-to-equity ratio	75%	
Debt cost	15%	
Equity cost	30%	30%
Marginal tax rate	28%	
Expected inflation	5%	
Weighted average cost of capital (nominal, pre-tax)		21.67%
Weighted average cost of capital (real, pre-tax)		15.87%

7.4 Revenue generated

Revenue refers to the amount received by a company from the sale of a given quantity of a commodity in the market and in this case, it's the electricity generated from the geothermal brine. Revenue is directly influenced by sales level as sales increases the revenue also increases. The revenue from this study was calculated as represented by Equations 26-29.

Proposed tariff to off taker =USD0.14/kwh (26)

Daily production $=\frac{\text{USD0.14}}{\text{kwh}} * 24\text{hrs} * 10000\text{kw} = USD\ 33600/day$ (27)

Monthly production $= USD\frac{33600}{day} \times 30 = USD\ 1008000/month$ (28)

Annual production $=\frac{USD1008000}{month12} = USD12{,}096{,}000/year$ (29)

7.5 Operating costs per year

Operating expenses are the expenses incurred in the company for its normal operational purposes and activities that generally include both the cost of products, services, sales and administrative expenses. For this study:

LCOE =USD 0.84/kwh (30)

Daily production $=\frac{\text{USD0.08}}{\text{kwh}} * 24\text{hrs} * 10000\text{kw} = 19200/day$ (31)

Monthly costs $= USD\ 576{,}000/month$ (32)

Annual production =USD 6,912,000$\frac{}{year}$(OpEx)$EBITDA = Annual\ revenue - OpEx$

$= USD\ 12{,}096{,}000 - \text{USD } 6{,}912{,}000 = USD5{,}184{,}000$ (33)

Assuming that: Tax is 8%, Depreciation 0.2% and Interest payable 3%

Net profit after tax=USD4,925,878……………………………………………(34)

7.6 Rate of return

The rate of return (ROR), measures the gain or loss of an investment over a given period. The ROR is expressed, as a percentage of the investment is cost. For this study, the ROR was calculated according to Equation 35.

$Rate\ of\ return = \frac{\mathbf{4{,}925{,}878}}{\mathbf{37{,}126{,}150}}\ \boldsymbol{x}\ 100$ =13.2 %..(35)

7.7 Payback period

A payback period is the time taken to earn back the cost of an investment. The payback period can be defined as the length of time taken by a project to reach a break-even point. For this study, the payback period was calculated according to Equation 35.

Payback period $= \frac{Initial\ investment}{Net\ profit\ per\ year} = \ 7\ years$ ………………………………(36)

8. Conclusion

There is potential for green electricity to be generated from geothermal energy resources abundant in Zimbabwe. Neohexane can be used as the fluid of choice to aid the conversion of the geothermal brine to electricity at 73 °C. The implementation of this project is quite capital intensive and a proposed off take tariff of USD0.14/kwh is proposed. A total of USD 40 million is required for generation of 10 MW with a rate of return of 13.2% and a payback period of 7 years for a plant life of 30 years.

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Biographies

Nodrax Chikwama is a Chemical and Process Systems Engineer from Harare Institute of Technology.

Prof. Mercy Manyuchi is a Professor in Chemical and Metallurgical Engineering at the University of Johannesburg in South Africa. She holds a Doctorate Degree from Cape Peninsula University of South Africa, a Master of Science Degree from Stellenbosch University and a Bachelor of Engineering Honors Degree from Zimbabwe. Her research interests are in waste to energy technology, mining waste management, engineering management, value addition of waste biomass and renewable energy technologies.

Prof . Nita Sukdeo is an Associate Professor in Engineering Management and the Head of Department for the Department of Operations and Quality Management, in the Faculty of Engineering and the Built Environment at the University of Johannesburg. Her research interests are in engineering management.