Presented at Short Course IX on Exploration for Geothermal Resources,
organized by UNU-GTP, GDC and KenGen, at Lake Bogoria and Lake Naivasha, Kenya, Nov. 2-23, 2014.

WHAT DOES GEOTHERMAL COST? – THE KENYA EXPERIENCE

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ABSTRACT

The industrial practice is to use the levelized cost of power to express the cost of power. On the basis of levelized cost, power projects are evaluated for approval, investment and/or financing by prospective investors. The levelized cost is premised on the net present value of cash flows arising from a power project. This cost includes all conceivable costs chargeable to the project. It is designed on the basis of the economic life of the project, the recovery of invested capital, operation and maintenance costs, and the generation of the desired return on investment or profitability to the investors. However, different variants of the levelized cost computation exist with and without taxes and depreciation. The computation that considers tax and depreciation provides better basis for investment decision.

The levelized cost of power is project specific and must therefore be established for each individual project. Published data indicate an upper limit of about 13 US cents per kWh for geothermal projects. Kenya's upper limit is about 10 US cents per kWh. There are many cost factors which may influence the levelized cost. The key among them are project size, well output, wells and plant costs, operation and maintenance costs, interest on debt, loan tenure, payback period and financial leverage. These factors may be categorized as installation or initial investment cost, operation and maintenance costs, capital and financing costs, economic factors costs and legal and regulatory costs.

Sensitivity analyses carried out using a generic financial model indicate that the project size, well output, payback period, loan tenure and financial leverage have an inverse relationship with the levelized costs while all direct costs and interest on debt have a direct relationship. It is further observed that the overall inverse relationship is predominant. The level of sensitivity of the levelized cost is not constant but varies with most cost factors. From this model, the project size, well output, payback and interest on debt may have the most significant impact on the levelized cost. The direct and inverse relationship of the various factors to the levelized cost means that the levelized cost can be optimized by undertaking informed cost factor selection so as to obtain the least cost factor combination.

Often times the installation or initial investment is used to give an indication of what geothermal would cost. This figure must be understood to represent the financial requirement and may not represent true reflection of what the levelized cost of power would be. The installation cost is also affected by the various cost factors and relates with them both directly and inversely. Published data indicate that installation costs ranges between 2.5 to 6.5 million US$ per MWe. Kenya average installation cost is about 3.6 million US$ per MWe. Kenya is increasingly employing early power generation using modular wellhead generation units.

Use of early generation can greatly reduce the installation cost as well as reduce the levelized cost. They can aptly be incorporated in a project to achieve optimization.

1. INTRODUCTION

1.1 Levelized cost of geothermal electric energy

The cost of generating geothermal electricity is normally expressed on a kWh basis otherwise referred to as the levelized unit cost of electricity. Levelized Cost of Energy (LCOE) is the constant unit cost (per kWh or MWh) of a payment stream that has the same present value as the total cost of building and operating a generating plant over its life (Levelized Cost of Energy Calculation:). Knight has defined the levelized as the times series of the capital and operating expenditure divided by the net power supplied, discounted to their present values (Knight, 2009). While Knight only considers capital and operational cost in his computation, other variants exist that include tax and depreciation (Levelized Cost of Electricity Literature Review). It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, cost of capital. It is a very useful industrial tool for comparing technologies with different operating characteristics. It is on this cost basis that the geothermal projects are evaluated for investment, approval and financing by prospective investors, governments, consumers or regulators and bankers or credit providers.

On average, the levelized cost for new geothermal projects ranged from 6 to 8 US cents per kilowatt hour. According to Ingvar (Geothermal Energy for the Benefit of the People) quoting UN World Energy Assessment Report indicates electrical energy cost for geothermal to be 2-10 US cents/kWh while Wikipedia (Geothermal electricity) alludes that the levelized energy cost is in the order of 0.04-0.10 € (0.05-0.13 US cents) per kWh. However, it is recognized that the cost for individual geothermal projects can vary significantly based upon the various cost factors, and that costs for all power projects change over time with economic conditions.

Kenya has fixed its feed in tariff for a geothermal plant of 70 MWe or less at 8.54 US cent per kWh. This cost further informs any other development. The country is unwilling to consider proposal whose levelized cost of power exceeds 10 US cents per kWh.

1.2 Investment cost

In addition to the levelized cost, geothermal cost is oftentimes expressed as an investment or installation cost per unit of plant capacity i.e. per MWe. This cost includes all capital expenditure necessary to construct a plant in addition to interest (cost of debt) during construction. It must be understood that the investment cost is a measure of financial requirement. Low or high investment cost may not necessary indicate lower or higher levelized cost electricity. This is because the operation and maintenance cost might outweigh the capital investment for lower investment cost resulting to high levelized cost and vice versa.

Wikipedia indicates that the investment cost for electrical plant construction and well drilling would be about 2-5 million € (2.6-6.5 million US$) per MWe of electrical capacity. In their report (Renewable cost of generation update, 2009), the California Energy commission indicates the projected installation cost for several plants to be between 2.603 and 5.329 million US$ per MWe. Kenya average installation cost as about 3.6 million US$ per MWe.

2. COST FACTORS

2.1 Installation cost

Installation costs are all initial costs excluding transmission and distribution that are incurred in the construction and commissioning of a power plant. The costs can be categorized into resource exploration, appraisal, production drilling and plant construction costs.

2.1.1 Exploration costs

The costs under this category include the cost of desk top data review, detailed surface study, infrastructure development and drilling of exploration wells. Depending on the whether in-house capacity or external consultants are used, the duration, the methodology used, remoteness of the resource, the detailed surface studies including the desk top may cost up to about 2 million US$. The infrastructure is a one off (fixed) cost that entails construction of access roads and water reticulation system. This cost will vary from project to project and is greatly influenced by the project's remoteness and availability of drilling water. It is common practice in Kenya to drill 3 – 4 exploration wells; one as a discovery and two as confirmation wells.

2.1.2 Appraisal costs

Appraisal entails drilling additional wells and undertaking a feasibility study. In Kenya it is typical to drill 6 – 9 appraisal wells. Thereafter, a bankable feasibility will be undertaken on the basis of which the prospect is approved for development. The feasibility study is mainly a desktop study that would include reservoir simulation and undertaking a preliminary design of proposed power plant. The feasibility study would cost about 2 million US$.

2.1.3 Production drilling costs

Production drilling entails drilling to provide adequate steam to operate a specific size of plant at full capacity and reinjection wells. The energy output from individual wells is highly variable, depending on the flow rate and the enthalpy (heat content) of the fluid, but is commonly in the range 5-10 MWe and rarely over 15 MWe per well (2010 Survey of World Energy). The world largest producer well produces about 50 MWe of steam. Several others wells world over produce about 30 MW and others as low as about 1 MW. Wells in Kenya produce between 1.5 MWe (old and shallow wells) and 18.5 MWe. Productivity is a affected by many variables including, well completion size, drilling fluids employed, permeability (primary and secondary), understanding of the field, the development phase, depth and the resource itself. Figure 1 indicates the observation made as drilling progressed at Olkaria IV. The first exploration well produced 1.5 MWe, the first appraisal 4.5 MW and the average production wells output at about 8 MWe.

Wells in high temperature fields are commonly 1.5-2.5 km deep and the production temperature 250-340°C. Kenyan geothermal wells range between a depth of 900 to 3200 m. A typical well in Nevada costs about $10 million to drill. In Kenya, drilling wells using owned rigs cost about 3.5 million US$ and about 6.5 million using hired rigs.

2.1.4 Power plant construction

Rarely does one find cost of geothermal generation equipment stated alone. In addition, the cost of plants would vary even for plants of the same size because they are designed to match the resource characteristics in particular turbine inlet pressure. Recent Kenyan experience has shown that different manufacturers may give greatly varying costs for the same size of plant and field. The price of generation equipment including installation may range between 1.5 million US$ to about 2.8 million US$.

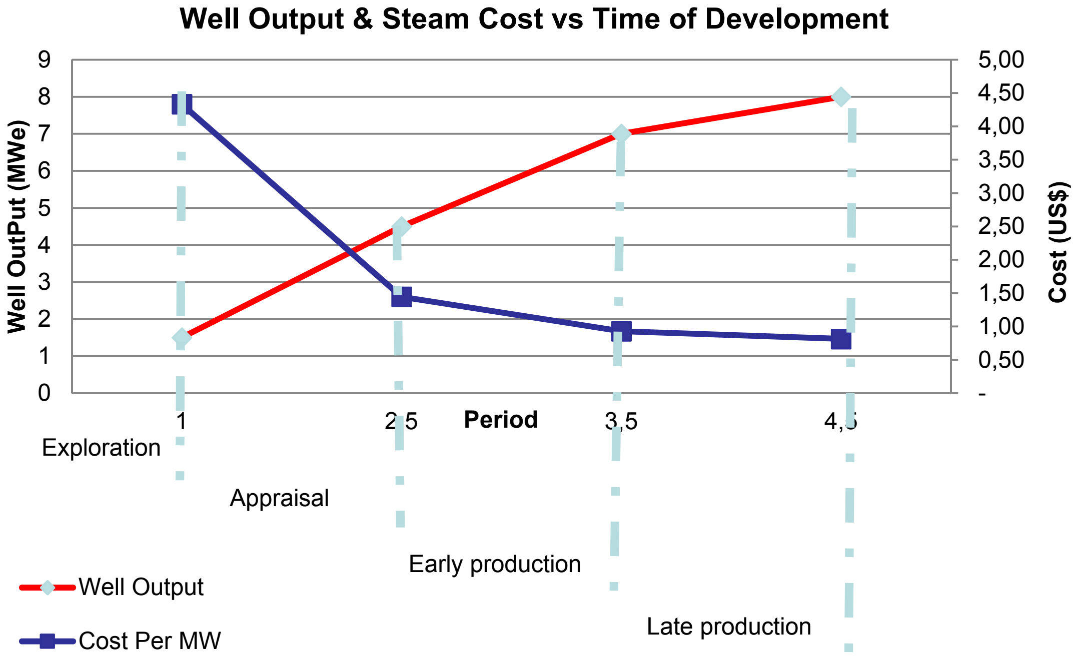

FIGURE 1: Well output over development time, Olkaria

2.2 Operation and maintenance cost

The operation and maintenance cost factors may be categorized as ordinary O & M costs which include staff, administrative and cost of spares, the plant inefficiency, reservoir management costs and cost of capital associated with increased working capital.

2.2.1 Ordinary O&M

The rate of operation and maintenance is fairly low for geothermal. The renewable energy cost of generation update (August 2009) indicates a figure of 0.0117 US$ per kWh. The Kenya experience indicates the cost to be about 0.00763 US$ per kWh (Least Cost Power Development Plan, 2009).

2.2.2 Plant inefficiency cost

Power plants suffer failures and breakdown. They do not operate at design capacity over their entire life but with time the efficiency decreases and the plants require timeout for inspection, repairs, refurbishment, rehabilitation and overhauls. The timeout costs money for maintaining staff and depreciation. This cost is captured through the capacity factor. The renewable energy cost of generation update (August 2009) indicate capacity of 90% for binary plants and 94% for the flash steam plants. In Kenya the range of 90 to 95 % has been used.

2.2.3 Steam field management cost

The steam field requires close monitoring during steam production to forestall serious steam declines, cold flow invasion, scaling and other adverse effects. Management and remedial works may be undertaken including drilling make-up and additional re-injection wells, work-overs, tracer injections and injection of scale inhibitors. These costs will vary greatly from one project to another and from one field to another.

2.2.4 Working capital

Firms require funds in their normal day to day operations. Besides paying out debts that become due, firms need to establish inventories of most critical spares. Experience has shown that lead times for some key power plant parts can be in excess of half year and it is not unusual to receive parts a year after making an order. Capital retained for this purpose will cost the company money to secure. However, the cost of working capital is relatively small.

2.3 Investment and financing cost

As noted in the previous section, implementation and operation of the geothermal projects requires funds. Geothermal projects are financed from equity, revenues accruing from the project and may include debt.

2.3.1 Equity

Investors provide equity in the hope that they will make a return on their investment. The return on equity (investment) constitutes a cost to the project. Investors are residual beneficiaries after payment has been done to lenders/creditor and preferential shareholders. Since payment of dividends is discretionary to the directors, investors offer the project a cushion in cash flow management. They bear greater risk than the other financiers and for this reason they require a higher return. In Kenya, the rate of return on equity (ROE) is 15% and above. The Government requires a ROE of 15%, while private investors would normally ask between 18% and 23% but it is not unusual to get higher requests.

2.3.2 Debt

Geothermal projects are capital intensive; large sums of money are required for their implementation. These sums of money are difficult to raise from a firm's internal sources. In addition, debt is much cheaper than equity. Further, firms prefer to lower their risk profile in a project by adopting project finance where other investors in particular lenders/creditors are invited to share profits and also bear some of the project risk. Thirdly, for most countries interest arising from debt is a deductible expense for income tax purposes. This provides price advantage normally known as a tax shield.

There are many sources of debt which include local and international commercial banks, bilateral and multilateral funding institutions, stock markets (bonds) and pension schemes. Figure 2 shows the various interest rate available to investors. Lending institutions and governments may provide interest free fund (grants) to a project, concessional finance or at commercial rates which also differ from one institution to another. The long term cost of capital from the local Kenyan commercial banks is about 12%. In addition, the long term cost of government infrastructure bonds are slightly cheaper.

2.3.3 Revenues

Revenue is another source of financing for a geothermal project. Revenues arise from the sale of electricity. While in principle equity and debt are designed to finance drilling of wells, buy and install the power plant, revenues are designed to generate resources used for operations, maintenance, debt payback, and to generate profits for the investors. To a firm, revenue costs are zero rated.

2.4.4 Payback period

Payback period is not a cost by itself. However, it represents choices that investors make in order to reduce risk. Power plants have a long life surviving several political regime changes. Investors are always concerned whether the successful regimes will maintain the same policy assuring the investor their return on investment. To minimize this risk, investors may require that a project pays back after

FIGURE 2: Interest rates for various financial sources

a specific period of time. A requirement for a shorter time will have a net effect of increasing the price of generated power.

2.4 Economic factors

2.4.1 Foreign currency exchange rate variation

In Kenya, generation costs are pegged on the US dollar in order to shield both the power off taker and the generator from currency exchange risks. However, the consumers pay for the electricity in the local currency. The cost of the exchange rate variation is assessed on a monthly basis which is then billed to the consumers directly.

2.4.2 Inflation

Over time money loses its value such that a fixed amount of money will buy fewer goods in the future. If left unaddressed, inflation can erode the investors return on investment and may lead to poor management and maintenance of the power plants. In Kenya, the cost of inflation is an aspect of the power purchase agreement and is adjusted on an annual basis.

3.5 Legal/taxation factors

Countries levy income taxes on all profit making entities except in exceptional circumstances. Further they may levy or exempt certain economic sector special taxes or grant tax incentives. In Kenya, the corporate income tax is levied at 30%. However, power plants are exempted from import duty and value added taxes. All power projects will pay an environmental certification levy equivalent to 0.01% of the project cost. It is also anticipated that with the effecting of the new constitution, royalties may be levied on projects by county governments in the future.

3. SENSITIVITY ANALYSIS AND RELATIONSHIP

3.1 Financial model

An analysis of the cost factors show interrelation between the various factors as well as the levelized and installation costs. The fixed cost and in particular the infrastructure cost is seen to be significant for a smaller sized project. However, as the project size increases, the impact of the fixed cost reduces and eventually become negligible. Further, well output is interrelated to the capital cost. As the well output increase the capital cost reduces. This also reduces cost of capital and if fixed financial leverage has been employed, the reduction further reduces the interest which intern reduces the tax shield and price advantage. It will also be noted that increase in the interest on debt have a double effect of increasing equity and additional debt requirement to cater for interest during construction. Increase in interest further improves the tax shield, hence reducing tax effect. Just like the fixed cost, the impact of the cost of drilling to the levelized generation cost reduces as the well output increases and with further increase in well output it becomes negligible. Because of these observations, it is most appropriate to investigate the relationships and sensitivity of the levelized and installation costs to the various cost factors by use of a model.

Pandey (Financial Management, ninth edition) states that investors or shareholders invest in order to increase their wealth. The objective of shareholders' of wealth maximization is an appropriate and operational feasible criterion to choose among the alternative financial actions. It provides an unambiguous measure of what financial management should seek to maximize in making investment and financial decisions on behalf of shareholders. The shareholders' wealth maximization is the net present value of cash flows (after tax) arising from an investment. This definition is consistent with the industrial calculation of the levelized cost of power generation except that it takes tax into consideration. This concept forms the basis of the model used to evaluate the relationship and sensitivity of the levelized and installation costs to the various cost factors.

Table1 enumerates the parameters chosen for the model. The model assumes a plant size of 100 MW and a fixed infrastructure cost. It ignores economic factors and changes in working capital.

4.1 Sensitivity and relationship

Figures 3 to 10 show a graphical representation of results of runs made from the model by varying one or several cost factors at a go while holding the rest constant. Table 2 is a more comprehensive representation of results of key runs undertaken for this paper. The results show that that the various cost factors related either directly or inversely to the levelized and installation costs. Well output, payback period, project size, financial leverage and loan tenure are inversely related to the levelized cost while interest on debt, drilling cost, return on equity, plant capital cost and operation and maintenance cost are directly related to the levelized cost. However, all the cost factors have varying degree of significance in their relationship to the levelized cost. The well output, payback period, project size, financial leverage, loan tenure, interest on debt, drilling cost, return on equity and plant capital cost are observed to have the highest degree of sensitivity to the levelized cost. Further observation of the graphical figures reveals that some cost factors do not have a constant relative change with the levelized cost but relative change changes with change of the cost factor. It is also observed that the various cost factors have also a direct and indirect relationship to the cost of installation even though some don't show any relationship.

A general analysis of the structure of the levelized cost (Figure 11) indicate that return on investment comprise the most significant component of the levelized cost followed by corporate income tax and depreciation respectively.

TABLE 1: Model input data

DEVELOPMENT PARAMETERS			
POWER PLANT		DEBT	
Plant size (MWe)	100	Interest	1.00%
Projected well output (MWe)	5	Grace period	7
Drilling Success Rate		Term	25
Exploration wells	50%	Arrangement fee	0.50%
Appraisal wells	75%	Commitment fee	0.50%
Production wells	90%	Pay-back period	17
Re-injection wells		Debt ratio/equity	70%
Ratio to production wells	1/5		2/7
Unsuccessful wells used for reinjection	30%	TAX	
Ratio of wellhead main plant	0%	Corporate tax rate	30%
GENERATION PARAMETERS		INFLATION AND EXCHANGE RATE	
Excess steam at startup	10%		
Steam decline rate	3%	SALES	
Plant capacity factor	90%		
Economic life (yr)	25	UNIT PRICE	0.1076
Service life (yr)	25	O&M COSTS	0.007
Operational hours per day	24	PLANT SIZE	100.00
Operational days per year	365	Ratio of production/injection wells	1/5
Parasitic load	3%	% steam wells used for reinjection	30%
EQUITY RATE OF RETURN		Estimated well output (MWe)	5.00
Expected rate of return on equity	15%	Drilling cost (US$)	3,500,000
		Drill pad cost (Kshs)	10,000,000
		Exchange rate (Kshs to US$)	85.00
		PIPELINE COST (US$/MW)	400,000
		PLANT COST (US$/MW)	1,500,000
		Well testing cost	30%

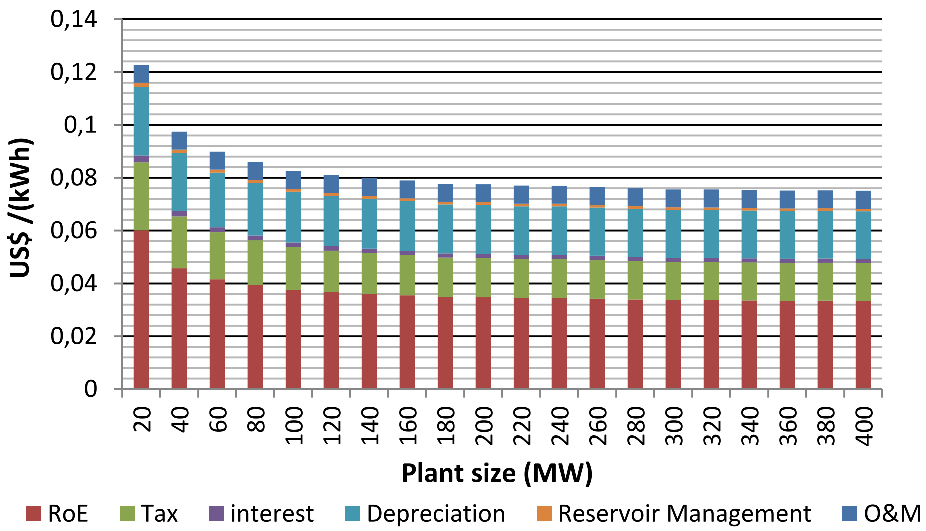

FIGURE 3: Levelized cost at various drilling cost and well output

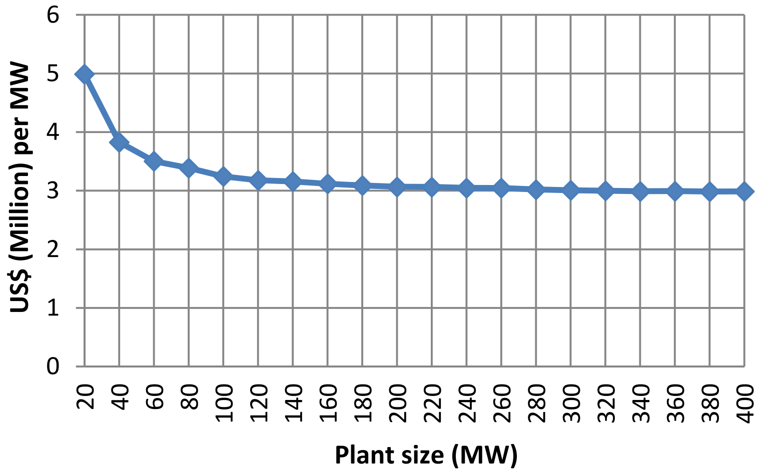

FIGURE 4: Installation cost at various plant sizes

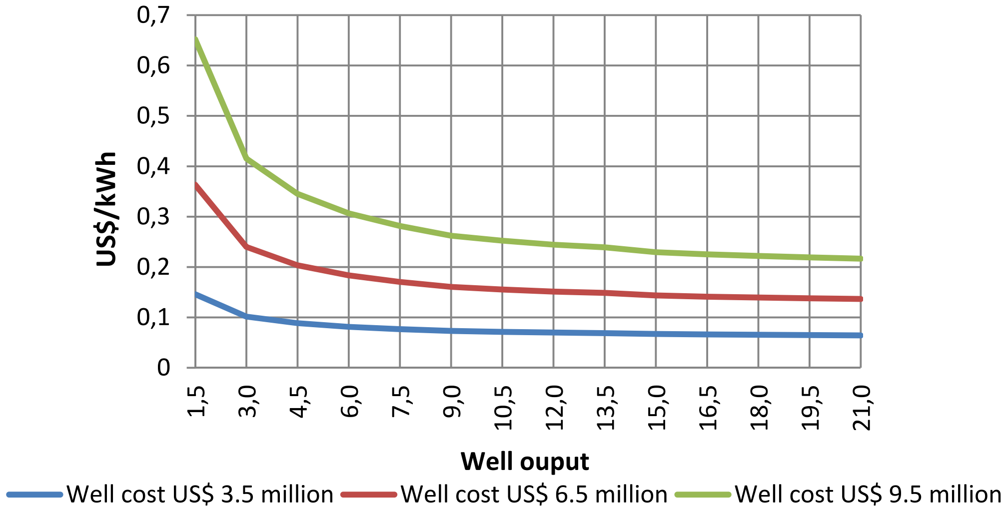

FIGURE 5: Levelized cost at various well outputs and drilling costs

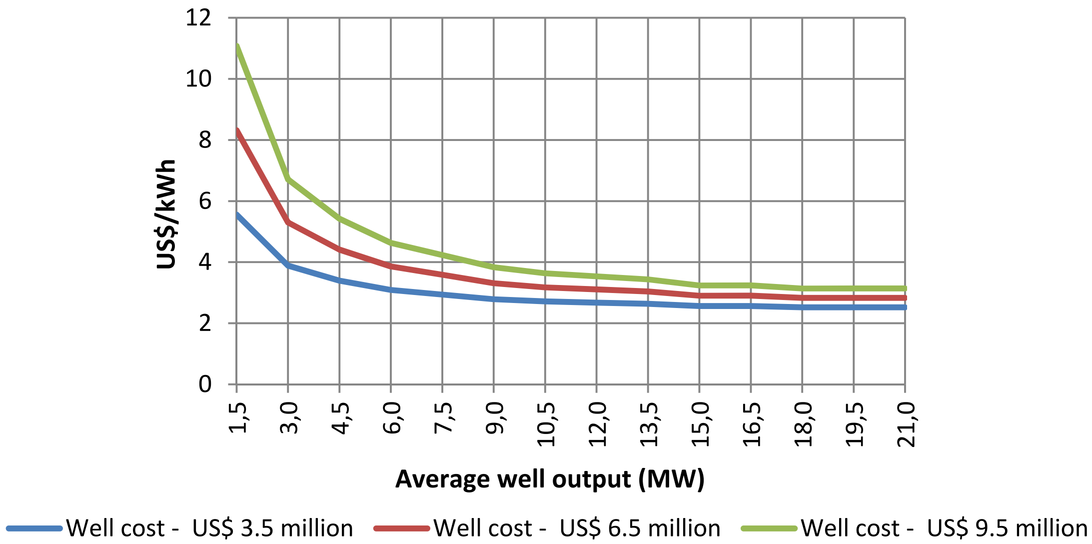

FIGURE 6: Installation cost at various well outputs and drilling costs

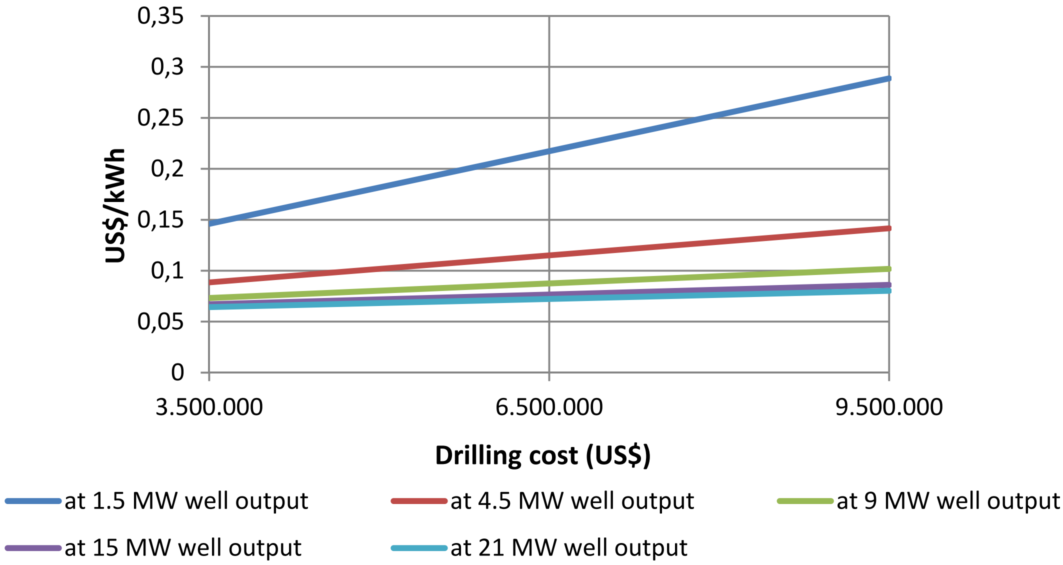

FIGURE 7: Levelized cost at various drilling cost and well output

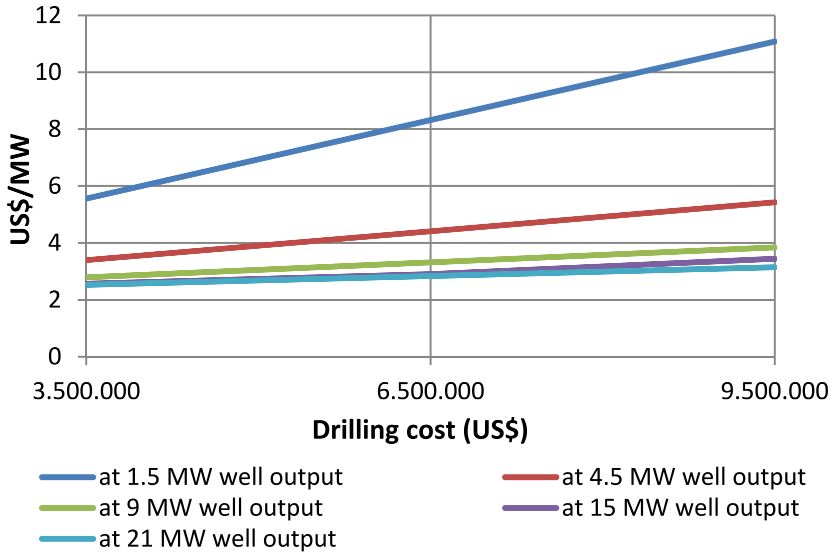

FIGURE 8: Installation cost at various drilling cost and well output

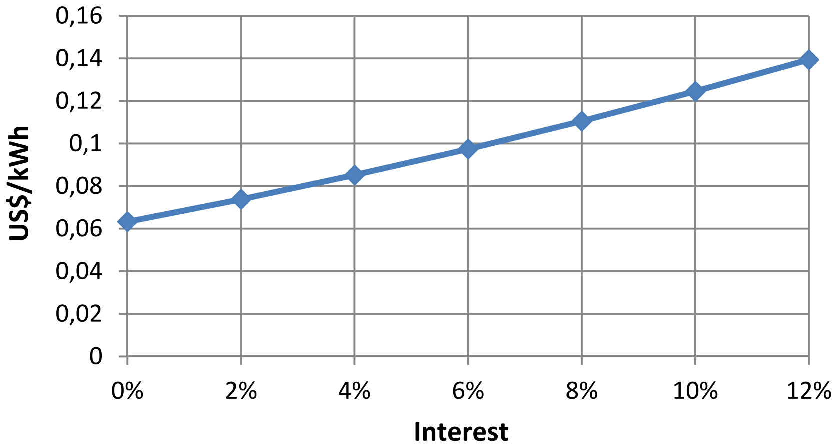

FIGURE 9: Levelized cost at various debt interest rates

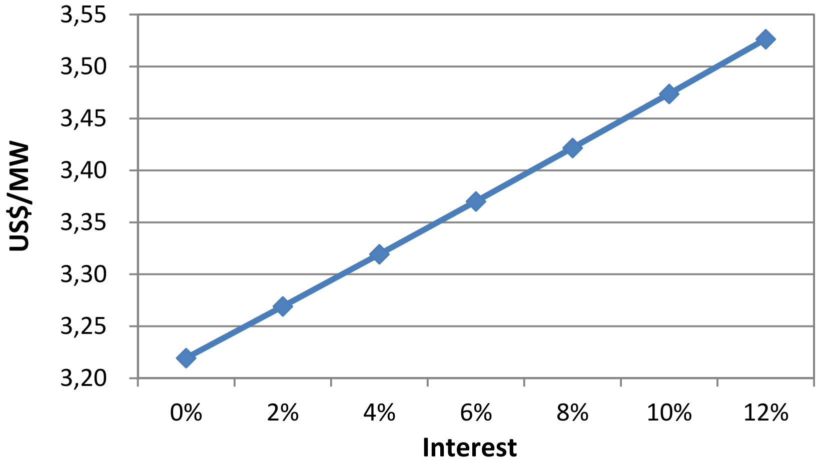

FIGURE 10: Installation costs at various debt interest rates

TABLE 2: Comprehensive result of model runs for various cost factors

Cost factor	**Relationship to generation cost**		**Relationship to investment cost**	
	Relative change	Relationship	Relative change	Relationship
Well output (1.5-21 MW)	55.7%	inverse	54.6%	inverse
Debt interest (0-12%)	54.6%	direct	8.7%	direct
Payback period (5-12 years)	50.9%	inverse	0%	
Drilling cost (US$ 3.5 -9.5 million at 1.5 MW)	49.4%	direct	49.8	direct
Project size/fix costs (20-400 MW)	35%	inverse	40%	inverse
Leverage (40-80%)	29%	inverse	0.4%	direct
Return on equity (12% - 22%)	29%	direct	0	
Plant capital cost (US$ 1.5 -3 million)	27%	direct	31.4%	direct
Loan term (7 -25 years)	25%	inverse	0%	
Early generation (wellhead, 0-60% of designated plant size)	18.8%	inverse	32%	inverse
Operation & Maintenance cost (US$ 0.005 – 0.009)	4.6%	direct	0%	
Steam decline (0-3%)	0.5%	direct	0%	

5. OPTIMIZATION

Given the behaviour of the cost factors (direct and inverse relationship), by proper selection of various cost factors a least cost factor combination can be realized. The project manager should seek to enhance the cost factor with an inverse relationship to the levelized and installation costs while limiting those with direct relationship. Further, managers may seek to minimize capital expenditure and tax while holding return

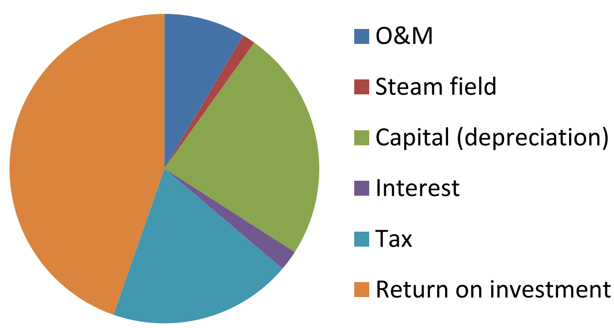

FIGURE 11: A general analysis of the structure of the levelized cost

on equity to the minimum for low levelized cost of power. Further, managers may design their projects to incorporate early power generation which has a major impact in reducing both levelized and installation capital requirement.

6. CONCLUDING REMARKS

i. The industrial practice it to use the levelized cost of power generation to express the cost of power. The levelized cost of power is a very useful tool for alternative power options. It is on the levelized cost that geothermal projects are evaluated for investment, approval and financing by prospective investors, governments, consumers or regulators and bankers or credit providers.

ii. The levelized cost is premised on the net present value of cash flows arising from a power project. However, different variants of its application exists some authors including taxes and depreciation while others don't. Investors engage in power projects to increase their wealth. The application that considers tax and depreciation provides better basis for investment decision.

iii. The levelized cost of power is project specific and must therefore be established for each individual project. Published data indicate an upper limit of about 13 US cents per kWh for geothermal projects.

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v. Sensitivity analysis carried out using a generic financial model indicate that project size, well output, payback period, loan tenure and financial leverage have an inverse relationship with the levelized costs while all direct cost and interest on debt have a direct relationship. It is further observed that the overall inverse relationship is predominant.

vi. The level of sensitivity is not cost but varies with most cost factors. From the model developed, project size, well output, payback, interest on debt may have the most significant impact on the levelized cost.

vii. The direct and inverse relationship of the various factors to the levelized cost means that the levelized cost can be optimized by undertaking informed cost factor selection so as to obtain the least cost factor combination.

viii. Often times the installation or initial investment has been used to give an indication of what geothermal would cost. This figure only represents the financial requirement and may not represent true reflection of what the levelized cost of power would be.

ix. The installation cost is also affected the by the various cost factors and relates with them both directly and inversely.

x. Published data indicates that installation costs ranges between 2.5 to 6.5 million US$ per MW.

xi. Use of early generation can greatly reduce the installation cost as well as reduce the levelized cost of a project. They can aptly be incorporated in a project to achieve optimization.

ACKNOWLEDGEMENT

The author thanks the United Nation University Geothermal Training Program, Management of Geothermal Development Company Limited (GDC) for providing the opportunity to write this paper, and the GDC's corporate planning team who critically reviewed the manuscript.

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