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VIABILITY OF WELLHEAD POWER PLANTS IN ACCELERATING GEOTHERMAL DEVELOPMENT IN KENYA: CASE OF MENENGAI

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ABSTRACT

Key words: geothermal development, wellhead power plant, feasibility, net present value, payback

There is an abundant geothermal resource in the Rift Valley in Kenya, according to the geothermal exploration performed in the region. Currently, two geothermal prospects are undergoing production drilling; two are undergoing exploratory drilling while four geothermal prospects are planned for exploration drilling. Geothermal Development Company (GDC) is the Kenya government state agency spearheading the exploration and development of geothermal resources. Geothermal power plant development takes a long time from the exploration stage until the power plant is operational. This usually puts financial pressure on both the projects and the executing agencies. With the planned geothermal development in Kenya, there's need to ensure the projects provide the highest benefits to developers and customers by thinking through the economics of the project. Geothermal projects should be feasible by understanding its risks, costs, and benefits. The objective of this work was to determine the viability of portable wellhead power plants (WHU) to accelerate the development of geothermal projects in Kenya before the commercial operation of central power plant. The study specifically focussed on the production drilling, well testing and plant construction and commissioning stages of the project development. A case study of Menengai geothermal field and a hypothetical steam field were used as scenarios where wellhead power plants were installed. The Net Present Value (NPV) method and payback period method based on the net power output were determined using the profitability assessment model. Possible Total Time differences between the production drilling and installation of the central power plants were considered. The study demonstrated that the use of wellhead power plants early in the development of geothermal resources was economically viable only if installed as a long term strategy for early revenue generation, continuous well testing and attracting private investors. The Wellhead units not only increases the NPV of the project but also increases the revenue of the project rather than waiting the construction of large sized conventional power plant with long lead time of around six years. Research results with a wellhead capacity of 5 MW reveals that at electricity prices of $0.088/kWh, the projected net revenue was $4.5 million and $6.3 million for time intervals (TI) of 3.5 years and total time interval (TTI) of 5.5 years respectively. It was also found that a 5MW wellhead unit generates positive Net Present Value of +4 and Internal Rate of Returns of 17% respectively over its economic life but the parameters turn negative over total time interval (TTI=5.5 years). The total capital outlay is estimated at 15 MUSD. This study proposes that there is need to shift focus from the traditional approach of installation of long lead time large conventional plants to a new approach that embraces deployment of short lead time (TTI) small sized portable wellhead plants for accelerated development and maximizing of revenue from green geothermal fields before commissioning of large geothermal plants.

1. INTRODUCTION

Geothermal energy is an attractive renewable energy and environmentally clean resource that Kenya has placed its power generation priority on to meeting it energy needs. For the last half a decade the geothermal industry has been in high gear in developing power from conventional geothermal power plants to meet the demand which is estimated to grow yearly at a rate of 11% from 2012 to 2,834 (Kenyan Ministry of Energy and Petroleum, 2015).

There are many reasons that can make electricity production from geothermal energy to be technically, economically and environmentally feasible. These reasons include its ability to act as base load (high capacity factor), low operational and maintenance cost and environmental friendliness.
The scope of this feasibility study paper is to evaluate the technical, financial and economic viability of generating power by using portable well head geothermal unit in Menengai field considering the current development, time value of money, and field characteristics. The motivation for this paper is based on the identification of a potentially viable wellhead unit utilizing the already available steam and using the already proven technology rather than waiting for the commissioning of the conventional plants which have long gestation periods. A 5 and 10 MW wellhead generating plants were assessed to determine if they will be beneficial alternative to Geothermal Development Company (GDC) with the time value being the key variable considered.

2. ACCELERATING GEOTHERMAL POWER DEVELOPMENT IN KENYA

2.1. Geothermal power development in Kenya

Kenya is estimated to have a geothermal energy potential of approximately 7,000 to 10,000 MW with high temperature geothermal prospects located in the Rift Valley running from the north to the south of the country. The country occupies the 8th position globally in geothermal power generation with an installed capacity of 632MW as at July 2016 as shown in Table 1. Geothermal accounts for 27.5% of the total installed electricity generation capacity of 2,341 MW, mainly from Olkaria geothermal power plants.

Table 1: Electricity power generation by source type in Kenya (*Source*: KPLC, May 2016)

Electricity Source	Installed MW	Effective MW	% (effective)
Hydro	820.73	800	35.2%
Geothermal	632.00	624	27.5%
Thermal (MSD)	716.32	690	30.4%
Temporary Thermal	30.00	30	1.3%
Thermal (GT)	60.00	54	2.4%
Wind	25.50	26	1.1%
Biomass	28.00	24	1.0%
Interconnected System	**2312.55**	**2,247**	**99.0%**
Off grid thermal	27.00	23	1.0%
Off grid wind	0.57	1	0.025%
Off grid solar	0.55	0	0.009%
Total Capacity MW	**2,341**	**2,270**	**100.0%**

The government of Kenya in 2013 set up an acceleration program to further generate 5000+ MW of electricity from various energy sources in the country and mainly from geothermal sources in Olkaria, Menengai, Baringo - Silali, and Suswa projects.

2.2. Kenya's initiatives to accelerate geothermal power development

Today, geothermal energy is the leading source of renewable electricity supply in Kenya. The rate of geothermal development and deployment in Kenya over the last decade has been phenomenal. The Sessional paper No. 4 of 2004 and the Energy Act 2005 ushered in a new era of energy sector institutional restructuring.

The government of Kenya through the Ministry of Energy and Petroleum has placed high emphasis on promoting and accelerating the development of geothermal power through the following sectorial, strategic, institutional and policy initiatives;

- *Favourable Government Policy*: The government introduced the Feed in Tariff Policy system in 2008 as a means of promoting power generation and attracting private sector investment in the renewable energy sector. Projects with a total capacity of 3,293MW have been approved for development (Kenyan Ministry of Energy and Petroleum, 2015. The wellheads currently in operation at the Olkaria Geothermal field are structured along the Feed in Tariff Policy framework
- *Government budgetary support in early resource exploration risks:* the government of Kenya and the World Bank has provided the necessary initial financing support for geothermal development during the exploration phase. This method has been applied in developing the Menengai geothermal field.
- *Attractive private investment climate:* the establishment of the public private partnerships policy framework to support private sector has spurred appetites from the privately owned power companies to lead in the development of the geothermal resources particularly near the Olkaria geothermal field.
- *Building in-country capacity:* Besides being the leading geothermal power producer, the country has considerably invested in training experts on different facets of geothermal technology both locally and international. The availability of competent human resource shall ensure geothermal projects are accelerated.
- *Deregulation and privatization of the energy sector*. The country initiated reforms which saw the unbundling of the geothermal sub-sector through the formation of separates entities to undertake steam development, generation, and distribution and transmission roles. The administrative reforms followed with the reduction in participation of the government in the sector.
- *Adoption of early generation techniques by the use of well heads*: The country adopted the use and deployment of portable wellhead geothermal plants to fast track the rate of geothermal power electricity supply to reduce the gestation period.
- Other initiatives includes high voltage transmission lines expansion and upgrade, enactment of laws such as the 2015 Energy Bill and the National Energy and Petroleum Policy 2015, and zero rating of import duty and removal of value added tax on geothermal energy equipment, materials and accessories.

All the sectorial, strategic, institutional, and policy initiatives put in place have significantly promoted the development of geothermal resources in Kenya by creating a conducive investment environment. These initiatives aim to minimise the risks associated with geothermal development, however the pace at which geothermal power plants are constructed is still slow. Therefore, there is need to accelerate the development of geothermal sources in the country to reduce electricity costs on consumers.

While all the initiatives discussed above are in place, the use of small wellhead power plants installed will provide the best technological initiative to generate electricity faster.

This paper seeks to test the economic viability of using the wellhead unit as an initiative to accelerate pace of geothermal development in Menengai.

3. USE OF WELLHEAD GEOTHERMAL POWER PLANTS

3.1. Kenya’s experience with wellheads - Current and planned

The wellhead power plants accounted for approximately 10% of the installed geothermal capacity in Kenya as at July 2016. Twelve wellheads plants have been successfully installed mainly at the Olkaria geothermal field with a generation capacity 65MWe (Bardarson (2016). A further 120MW of installed wellheads capacities are scheduled for commissioning before end of 2017.
With the successful deployment of the above pilot portable power plants in Olkaria and Eburru, there has been a growing interest from generators to further invest in more units in other fields currently under development to leverage on time and revenue.

3.2. Expected benefits and impacts of use of wellhead power plants

The application of wellhead units has positive economic benefits. The benefits of using wellhead power plants, as suggested by Sutter et al 2012, include acceleration of geothermal development by providing electricity to geothermal drilling rigs, integration of power generation with agribusiness and tourism, and providing investment opportunities. This paper delves in the use of wellheads to accelerate geothermal power projects in Kenya, either through early generation to the grid or power supply for drilling purposes.

The following are specific expected benefits of wellhead power plants to a geothermal field developer:

a. Boosts supply new electricity into the national Grid for meeting increasing demand for electricity in Kenya and therefore contribute to the achievement of the 5,000+MW government target.
b. It speeds up delivery and access to electricity and generating early revenue (time value of money) to the field developer as the project awaits the installation of conventional geothermal power plants. The portable geothermal stations take about six months to complete construction unlike the typical geothermal plants.
c. Through early generation, wellheads eases dependence on the exchequer and external donors for further financing of the main power plants and other projects
d. It can reduce associated drilling project costs by displacing diesel during drilling and providing power for the camping facilities
e. The installation of the wellheads power plant shall provide filed developer with a platform to train its staff on the operations and maintenance aspects of power plants before full-scale rollout of conventional geothermal power plants.
f. Wellheads are economically affordable, easy to install and cheap to maintain and operate
g. The wellheads units are portable and can easily be moved to other geothermal areas.
h. The wellhead units allow the tapping of geothermal wells almost immediately after drilling as the wells undergo testing.
i. The wellhead comes in standardized design and construction, and highly reliable.

The risks associated with geothermal power project reduces as the project progresses along, the risks are even minimised further when smaller power plants are installed as opposed to bigger plants.
The risks in geothermal power project reside in the development and operation stages, Rakhmadi et al 2015. The three (3) risks associated with the development stage include;

1) Resource risks which describe the difficulty of estimating the geothermal resource capacity and the large costs associated with addressing the uncertainty which make this risk significant and worthy of attention, Gehringer et al 2012.
2) Delays and cost overruns risks can occur as a result of unavoidable events during the drilling process and power plant construction phase.
3) Financing risks are associated with the long lead times between the project initiation and how fast revenue is generated. Reduced resource risks proportionately reduce the financial risks.

The deployment of wellhead power plants can reduce the risks of a geothermal power project through early generation of revenue compared to the conventional power plant. In the Menengai geothermal field, the resource risks have been reduced significantly through an accelerated drilling program and proving of commercial amount of steam.

It's strongly thought by the authors that if the steam capped at the wellhead was used as early as it was proven, the project could have been earning revenue progressively. Figure 1 shows the project timeline and the various milestones achieved.

3.3. Geothermal power plants types

The power plants are the energy conversion units in geothermal development. The power plants convert the geothermal heat into electricity by operating between the high temperature of the geothermal fluid and the low-temperature of the environment.

The three traditional types of geothermal power plants are: (1) direct dry-steam, (2) flash steam (single or double) and (3) binary power plants, DiPippo 2005.

Direct dry-steam plants use steam piped directly from a vapour-dominated reservoir. Dry-steam plants tend to be simple in design and relatively cheap. There are two known dry-steam geothermal reservoirs in the world, Lardarello and Geysers in Italy and USA respectively, DiPippo 2005.

Flash steam power plants are the most common power plants type for liquid-dominated geothermal systems. The geothermal fluid is passed through a cyclone or horizontal separator that flashes the fluid into steam and brine. The brine is transported to the power plant, while the brine is re-injected. Flash plants are used with liquid dominated reservoirs with temperatures greater than 160^{o}C, Bronicki 2002. The flash plants are categorised into single-flash, double-flash or triple-flash depending on the operating pressures of the well(s).

The flash power plants can also be grouped as back-pressure or condensing. The turbine of a back-pressure power plant discharges the steam to the atmosphere, while a condensing turbine discharges steam to a condenser at a lower pressure than the atmosphere. The backpressure plant is less efficient than a condensing plant.

Binary plants are used with low- to medium-enthalpy geothermal resources (less than 190^{o}C), Bronicki 2002. The power plant cycle is based on organic Rankine cycle (ORC), where the geothermal fluid is used as the heat source to raise the temperature of a secondary working fluid (organic) in a heat-exchanger of the Rankine cycle. For a two-phase geothermal reservoir producing fluid of between 10 – 30% steam qualities, binary plants are considered more efficient and cost-effective, Bronicki 2002.

4. CASE OF MENENGAI GEOTHERMAL FIELD

4.1. Overview of Menengai Geothermal Field

Menengai, the third prospect to be developed outside of Olkaria and Eburru prospects, is located within the Kenyan Central Rift Valley, North of L. Nakuru and South of L. Bogoria. It is located within a region of the intra-continental crustal triple rift junction. The Menengai complex is a Quaternary caldera volcano built of trachyte lavas and associated intermediate pyroclastic. The field measures approximately 850 km^2.

The geothermal system at Menengai is associated with volcanic activity and it is thought that hot intrusions and magma chambers constitute the heat source for the system. Detailed exploration in the Menengai geothermal system began in 2004 while Geothermal Development Company (GDC) commenced drilling early 2011 and by October 2015, a total of 30 wells had been completed. Within the same period flow tests were performed on the productive wells.

4.2. Project status

Menengai geothermal field is at its early stages of development by Geothermal Development Company (GDC). Figure 1 shows timeline for drilling and well testing in Menengai geothermal field.

The first exploration well in Menengai (MW-01) drilled in 2011 identified a two-phase resource of about 300^{o}C. Reservoir evaluation of Menengai geothermal field in 2013 indicated that the reservoir consists of a shallower and deeper system with reservoir temperatures of between 190 – 270^{o}C and 280 – 340^{o}C respectively. The geothermal reservoir at Menengai is characterised as high temperature, high enthalpy, and two-phase reservoir according to classification by, Saemundsson 2009.

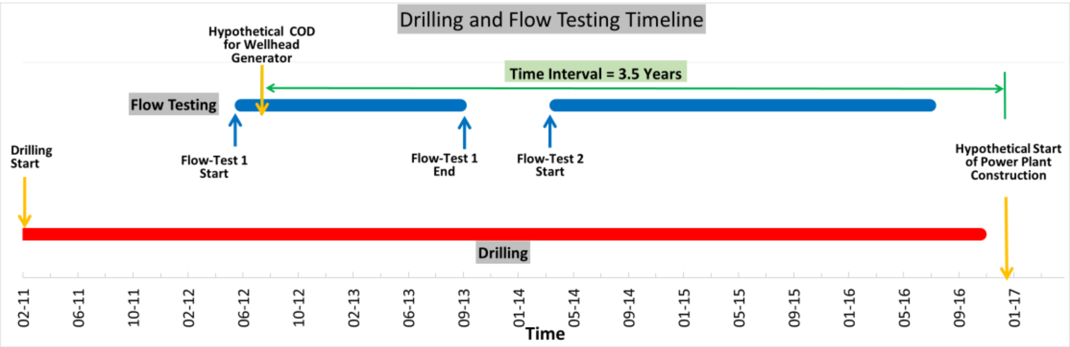

Figure 1: Shows the chronology of drilling and well testing in the field.

Power plant construction process at the Menengai geothermal field has commenced with the agreements between GDC and three (3) operators to develop a 105 MWe central power plants. The power plants shall be developed on a build-own-operate (BOO) basis. A steam gathering system is under construction to collect steam the wellheads from and supply to the power plants. The actual installation of the power plants has not commenced.

The choice between the use of central power plants and wellhead power plants depend on various factors such as topography, geothermal fluid characteristics and cost of the power plants, Geirdal et al 2013. From recent conference in Iceland, the deliberations concluded that the cost of small-scale power plants (like wellhead power plants) is similar and more often cheaper than conventional large-scale power plants (www.geg.no).

Extensive production testing has been carried out for the discharging wells. Production performance for each well has been determined by estimating its productivity curve and the enthalpy. The productivity curve relates the mass-flow rate of geothermal fluid from the well to the wellhead pressure.

The geothermal fluid is a mixture of water and steam and it is characterized by the steam content and total enthalpy. These characteristics are determined by the pressure of production and chemical composition of the fluid. The performance for each production well is indicated by the output curve, which relates the flow-rate of the fluid to the well head pressure (WHP). The production from the wells is determined by the chosen WHP.

The geothermal reservoir in Menengai produces geothermal fluid with steam quality range of 0.3 – 0.9 approximately which makes it suitable for single flash condensing power plant. Single flash condensing plant configuration have been used in Olkaria geothermal field for the wellhead plants, therefore it is a proven technology. The double flash and binary were considered unsuitable at this stage of project development. The operating wellhead pressures were considered low for a double flash and it was assumed that the wellhead plant will be located on or close to the wellpad hence due to space considerations binary plants were deemed not suitable in this case.

The boundaries of the wellhead power plant were defined at the fence of the plant as: steam supply from the well(s), condensate return from power plant, control & monitoring signals and power supply to the grid. The definition of the interfaces will simplify technical, contractual and economic analysis of the power plant.

4.3. Conceptual Design for the Wellhead Power Plant

The layout of the conceptualized wellhead power plant is as shown in figure 2 below. The typical size of wellpads measure approximately 100 by 100 m while the space requirements of a wellhead power plant could be a minimum of 60 m by 30 m. therefore, a wellhead plant can be accommodated sufficiently on a wellpad. The wellhead includes a separator, turbine-generator assembly, silencer, control room and cooling towers.

Power generated at the wellhead can be evacuated using modular sub-stations or mobile substations otherwise by the transmission line if it has been constructed.

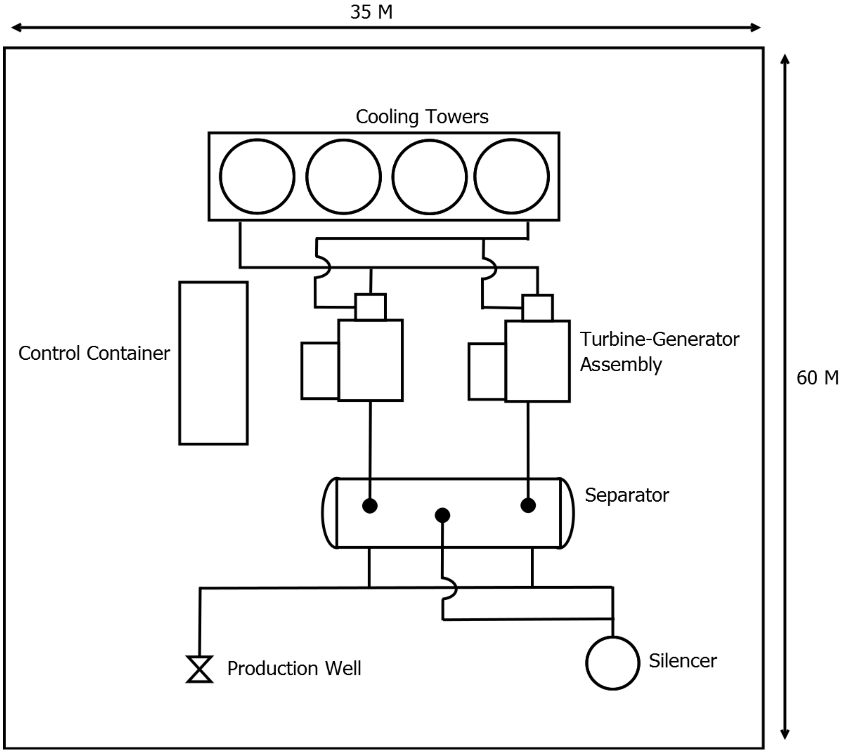

Figure 2: Layout of a wellhead power plant

4.4. Calculation of the Time Interval (TI) between drilling program and power plant construction

Geothermal project development can take a duration of between 5 to 10 years and can be divided into various phases, Gehringer et al 2012:

- Phase 1: Preliminary Survey
- Phase 2: Exploration
- Phase 3: Test Drilling
- Phase 4: Project Review and Planning
- Phase 5: Field Development
- Phase 6: Power Plant Construction
- Phase 7: Power Plant Start-up and Commissioning
- Phase 8: Power Plant Operation and Maintenance

This study shall focus on the duration between field development and end of power plant construction (COD) phases of the geothermal project. The objective being to determine the time lapses after commercial steam has been proven on already drilled wells and the commissioning of the central power plant. The time interval (TI) and total time interval (TTI) are important to determine the viability of installing wellhead power plant before the commissioning of main central plant.

Figure 1 shows a visual representation of drilling and flow testing timeline for the Menengai geothermal field. TI was determined from the middle first episode of flow testing to the time the construction of the central power plant will commence. It was assumed that the construction of the central power plant will commence in December 2016 and will take approximately 2 years. From Figure 1, TI = 3.5 years. The total time interval (TI) until the commercial operation date (COD) of the central power plant will be TTI = 5.5 years. Therefore for analysis that follows below, the time interval,TTI = 5.5 years as well as for the entire economic lifetime of the wellhead will be used to determine the economics of the wellhead power plant

5. FINANCIAL AND ECONOMIC ASSESSMENT

A financial and economic assessment of the well head generating unit over the Total Time Interval (TTI) and projected over the project life was carried out to determine if a 5MW wellhead project is financially or fiscally sustainable. The returns from the well head unit over 5.5 year time interval is a key decision making parameter for evaluating the benefits of early deployment.

The prospective costs for the plant are those of an already defined site, Menengai geothermal field, with the initial cost of the steam development including exploration, well drilling and well testing not considered. The cost estimates are based on expert opinions and historical data from similar projects in Eburru and olkaria geothermal fields.

A profitability assessment model based on excel spreadsheet and developed by Jensson (2006) was applied to calculate the project's net present value (NPV), internal rate of return (IRR), free cash flows depending on a number of parameters including the investment costs , project financing costs, and electricity prices. This financial model is well documented and a detailed description published by Jensson (2006).

5.1. Technical assumptions for the WHU

A single flash condensing wellhead power plant size of 5MW was considered. This power plant type is the most popular with 28 units installed worldwide as at June 2016.

The following table shows the technical assumptions made for the modelling exercise.

Table 2: Technical assumptions for the 5MW WHU

Technical Assumptions	Value	Unit
Wellhead power plant capacity	5	MW
Wellhead Economic life	20	Years
Number of operation hours	8768	h/y
Plant steam Consumption	8	t/hr/MW
Electricity Costs (Feed in tariff)	8.8	US Cents kWh
Capacity factor	95	%
Wellhead procurement Start date	June 2012	Date
Wellhead Commercial Operation Date (COD)	July 2013	Date
Conventional Plant construction start date	Dec 2016	Date
Conventional Plant Commercial Operation Date (COD)	Dec 2018	Date

The time taken from procurement and construction of the wellhead up to commissioning is estimated to take less than 12 months, while the construction of the conventional plant is projected to take 24 months.

Average steam output from each well was assumed as 5MW. For this study one well was assumed to supply the well head.

5.2. Modelling Costing assumptions for the WHU

Based on the selection criteria and suitability of technology of choice as discussed in section 4.2, the capital cost for a single flash condensing plant considered is 2,500$/kW (Sanyal, 2004). The capital cost for the well head plant including generator set, cooling towers, electrical, control and protection system, supply, installation, and commissioning are included in the cost estimates. This study also assumes that the costs for engineering, supervision and commissioning to be undertaken by a contractor is 10% of the total capital cost.

For the purpose of this analysis the costs for the power evacuation lines, access roads, land rights, permits, drilling, water system and steam gathering system have not been factored. These costs are assumed to be included in the cost computations for the conventional power plant.

A summary of key breakdown of plant cost assumptions is provided in the Table 3 below;

Table 3: Costing assumptions for the 5MW WHU

Cost Assumptions	**Value**	**Unit**
Power Plant Capital Cost	2.5	MUSD/MW
Evacuation Facilities	0.5	MUSD
General Contingency – 2.5%	0.4	MUSD
Corporate tax	30	%
Fixed O&M	0.5	MUSD/yr
Repayment period	10	years
Months per year	12	months
Interest rate of loan	8	%
Local taxes	30	%
Equity/Debt ratio	70:30	%
Total Time Interval	5.5	Years

6. DISCUSSIONS OF MODEL RESULTS

The total estimated Capitals costs associated with a single flash condensing wellhead power plant of 5MW size wellhead plant has been estimated at $15.4 million. With a 5MW well head unit selling electricity to the national grid at 95% net plant capacity, the plant would produce 42 TWh per year. At the electricity prices of $0.088/kWh, the projected annual net revenue is $7 million in its first 5.5 years (TTI) of operation, and $ 32 million in its economic life. The wellhead plant is projected to break even in the fifth year of operation.

The results of the Profitability Assessment Model is shown in Table 4

Table 4: Revenue results for the 5MW WHU

WELLHEAD REVENUE ANALYSIS	TTI (5.5 Yrs)	ECONOMIC LIFE (20 Yrs)	UNIT
Net Cash flow	6.3	32	MUSD
NPV Total Cash Flow (Project)	-5	4	%
IRR Total Cash Flow (Project)	-3	17	%
NPV Net Cash Flow (Equity)	0	3	
IRR Net Cash Flow (Equity)	17	35	%
Discounting Rate (MARR) Total – target rate	12.	12.	%
Discounting Rate (MARR) Equity– target rate	18	18	%

From the analysis, the proposed wellhead generates positive Net Present Value (NPV) of +3. The project also results in both project and equity IRR and being greater than the project and equity Marginal attractive rate of return (MARR) as indicated in Table 5 here below;

Table 5: Project decision rule for the 5MW WHU

Decision	TTI (5.5 Yrs)		ECONOMIC LIFE (20 YRS)	
	Measure	Decision Rule	Measure	Decision Rule
Project IRR vs. Project MARR	-3%<12%	*Not Viable*	17%>12%	*Viable*
Equity IRR vs. Equity MARR	17%<18%	*Not Viable*	35%>18%	*Viable*
Project NPV	-5	*Not Viable*	+4	*Viable*
Equity NPV	0	-	+3	*Viable*

Economic and financial evaluation was further conducted to assess a single 10MW wellhead generating unit and check if deployment of a larger plant is viable over the same period TTI = 5.5 years. The cost of the project and lifecycle costs were estimated. This scenario assumed total capital costs of $29M to cover the costs for the generating unit at $2.4 million per MW, transmission lines, EPC contracts and contingency. All other assumptions and parameters are similar to the 5MW wellhead unit.

The results from this scenario suggested that a larger size wellhead plant of 10MW just like that of a smaller unit of 5MW was economically unviable over TTI but viable over the 20 year period. The economic unattractiveness of the larger plant could be explained by the short TI and TTI and the large initial investment expected to be recovered.

Despite the 5 MW wellhead power plant being unviable, it should be noted the analysis was based on higher level costing estimates found in published literature. If more accurate costs could be applied probably the viability of the wellhead generators can be greatly improved. Similarly, when the motive of installing the wellhead generator is to supply power to a drilling rig, then its likely to operate for a longer time interval hence improving its viability.

7. CONCLUSION

This study presents the technical and economic assessment of a 5MW wellhead geothermal plant for accelerating geothermal development in Kenya. The Menengai geothermal project was used as a case study. The reservoir characteristics of the Menengai were evaluated and the single flash condensing plant was selected as the best option for that kind of field. A profitability assessment model based on excel spreadsheet was used to assess if the plant is financially feasible.

From the modelling results undertaken, and the accompanying discussion, it was demonstrated that deployment of a single flash condensing wellhead power plant size of 5MW early in the development of geothermal resources at the Menengai field is feasible over the 20 year period but unviable over time TTI;

- Based on the assumptions made for the reservoir and well flow characteristics, and the commercial parameters used in the financial model (loan term and interest, interest on loan, debt to equity, inflation rate and electricity tariff rate, it is found that a 5MW wellhead unit generates positive project and equity Net Present Value (NPV) of + and +3 respectively over its economic life. In addition, the project and equity IRR of 17% and 35% respectively are greater than the targeted project and equity Marginal attractive rate of return (MARR) or hurdle rate of 12% and 18% over the same period. These parameters demonstrate that the project is financially and economically attractive over a 20 year period.
- At the electricity prices of $0.088/kWh, the projected annual net revenue over time interval TI i.e. the first 3.5 years of operation is $4.5 million and $6.3 million over total time interval (TTI=5.5 years). These represents revenues opportunity which could have otherwise been lost should the project have waited until the commissioning of the central power plant. From the model, the wellhead is projected to generate $32 million in its economic lifetime. It is therefore a profitable project.
- The total capital outlay of a 5MW wellhead investment is estimated at 15 MUSD and translates to 2.5MUSD per MW. Annual power plant operational cost is estimated at $0.70M.
- The wellhead proposition accelerates delivery and access to electricity and generating early revenue to GDC within the first 2-3 years of drilling start as the project awaits the installation of long-time-lag conventional geothermal power plants. This allows faster returns on project investment.
- The single flash well head condensing power plant is a proven technology that suits well with the geothermal reservoir characteristics in Menengai
- Deployment of a 10MW wellhead plant is not feasible over the TI and TTI due to high capital costs associated with the large capacity plant but feasible over a 20 year period

In conclusion, this study demonstrates that besides its high availability, reliability and portability, a 5MW well head generation unit at the Menengai geothermal field (greenfield) is technically, economically and financially feasible project over a long time (economic life) and also the right solution for GDC to meeting its revenue needs. Geothermal rich countries undertaking development could therefore consider embracing the deployment of short time, small sized portable wellhead plants as a way of undertaking long term testing of green geothermal fields to generate revenue and increase private sector investor confidence. The wellhead units are also projected to optimize returns as early as the wells are tested as the fields awaits installation of long lead time large conventional plants which is a traditional approach of geothermal development.

The economics of the WHU could even improve further if the unit could be financed through internal revenues, cheap financing options and grants.

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