Viability of Wellhead Power Plants as substitutes of Permanent Power plants in Grid Electricity Generation

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Abstract
A conventional geothermal power plant will take generally between 5 and 10 years with significant upfront costs and risks. On the other hand, a wellhead power plant will take between 3 and 6 months to install and commission upon successful well drilling and testing. The overall objective of this research is to determine the feasibility of geothermal wellhead power plants as substitutes of central power plants in permanent power plant development. Wellhead power plants can be used as temporary plants during geothermal project development or as permanent power plants for the entire production life of a geothermal well. This study investigated the financial, technical and environmental sustainability of permanent wellheads in geothermal power project execution and power generation. Examined was technical, economic and environmental feasibility of operating wellhead power plants in Kenya. The study showed that the wellhead power plants have early and quicker return on capital and are technically feasible in terms of operating load and capacity factors which is lower than the conventional plants but still competitive compared to wind and solar. This implies that wellhead power plants are viable as temporary plants and permanent plants but remain inferior to central power plants while long term viability needs further investigation.

Keywords: Geothermal electricity generation; wellhead power generation; geothermal power generation, financial viability, modular power plants; technical viability.

1. Introduction

Electricity continues to account for over 40% of combined global energy demand and consumption and remains a good measure of a country’s economic performance and progress (Rahman & Castro, 1995). Electricity generation alone accounted for 42% of global CO2 production in 2013 followed by transport which contributed 23% (Günkaya, Özdemir, Özkan & Banar, 2016). The rapid growth in global electricity demand has led to increased consumption of fossil fuels and massive discharge of pollutants to the ecosystem. This environmental concerns have led to increased demand for renewable energy resources utilization (Kabeyi & Olenwaraju, 2020). Among renewables, the geothermal energy has the advantages of having higher reliability, sustainability of supply, greater capacity factor and less ecological impact (Liu et al. 2017). Geothermal energy has significant potential globally for use in heat and electricity generation applications depending on the geothermal resource potential and characteristics (Tunc, Sisbot, & Camdali, 2012). The most attractive features of geothermal energy is its potential to generate zero carbon emissions that can yield a 24 hour constant power output ideal for base load electricity generation and supply which ensures high capacity factor and high load factor (Bahadori, Zendehboudi, & Zahedi 2013). However its global development has been slow (Kabeyi, 2019), for example it realized a paltry 0.6% growth between 2000 and 2007 (Bahadoni, et al, 2013).

The main challenge facing geothermal development is the long gestation period and high upfront costs and risks involved in resource identification and development (Kabeyi & Olanrewaju, 2020; Kabeyi, 2019; Kabeyi, 2020). Wellheads are small geothermal power plants with installed capacity of between 1MW and 10MW, installed at the well pad of a geothermal well. They can be installed in as short as 6 months to commissioning. They are used to optimize production characterized of a given well pad. Which are used to overcome the shortcomings of traditional
methods of exploiting geothermal resources such long gestation periods of up to 10 years. Table 1 below compares the difference between a central power plant and a single wellhead.

The main objective of this study is to examine the use of wellhead power plants as alternative option for permanent geothermal power plant development as a means of accelerating geothermal electricity generation in a safe, cost effective and technically feasible manner.

2.0 Problem Statement

Geothermal power plant projects are highly complex and capital intensive with huge upfront costs in resource identification and development (Palsson, 2017). It takes up to 10 years to develop a geothermal central power plant in an undertaking that involves a lot of upfront costs in drilling and exploration. These investments are not attractive to investors and financiers (Kabeyi, 2020). It is difficult to drill all the required geothermal wells before one can secure financing (Kibet & Bwoma, 2015). Even after drilling and testing of a well, it takes about 2 years to construct a 50-70 MW central power plant. This construction phase involves development of steam gathering system, re-injection system, powerhouse construction, installation of equipment, power transmission system and finally commissioning plant (Kibet & Bwoma, 2015). By using wellhead power plants, it is possible to realize early cash, avoid diesel costs in field operation by generating own power and enabling long term tests on wells while generating useful power (Kabeyi, 2020). It is possible to design wellheads specific to specific well conditions and characteristics leading to higher efficiency and wellheads have been effectively used in the short-term to generate power during field development, but there is no agreement on long term viability of wellhead power plants as compared to conventional central power plants (Long, Raman, & Harvey, 2012). Whereas the temporary use of wellhead power plants makes economic and technical sense, the long term or permanent use needs further investigations which is the subject of this investigation and the results will be indicative of project viability (Kabeyi, 2019a, 2019b).

3.0. Geothermal Electricity Generation

Geothermal energy is heat energy that is constantly generated by the earth from the decay of radio-active materials such as thorium, uranium and potassium. Geothermal energy has been used for millions of years that is for cooking, heating, bathing and treatment in the form of hot springs and hot pools. Geothermal energy has also been used for production of salt from brine. Mythical connotations have also been attached to it, for instance, natural springs have been taken as a representation of life and a symbol of power (Stober & Butcher, 2013). Geothermal fields are found mainly along the boundaries of tectonic plates and in volcanically active areas. Rich hydrothermal resources are found in only a few areas in the world, currently the hydrothermal resources are the most viable economically (Loksha, Gehringer, & Loksha, 2012). The main challenge facing geothermal electricity development is high project costs and long gestation period (Kabeyi, 2019).

Geothermal power projects require significant investment in infrastructure prior to resource exploration and development. This includes development of access roads, development of workers camps, water, electricity and telecommunication infrastructure (Monroy, 2016). Exploratory drilling alone which is unattractive to investors may cost 20-30% of total project cost (Gehringer & Loska, 2012). Additionally power plants incur significant operational costs which are often independent of the power plant size and technology used (Palsson, 2017).

3.1. Types of geothermal power plant technology

3.1.1. Dry steam power plants

Dry steam power plant utilize steam directly from the well by routing it directly to the turbine where it is used to generate electricity. This type was the first geothermal power plants to be installed. Dry steam power plants are currently in use at the geyser in the USA (Kati, et al, 2010; Mburu, 2009).

3.1.2 Flash power plant
In flash steam power plants, steam is separated from the water and is routed to the turbine where it is used to produce power. After leaving the turbine, the steam is condensed creating a partial vacuum which maximizes the power produced by the generator.

### 3.1.3. Binary cycle power plant

Binary cycle power plants are utilized where the geothermal fluids have temperatures less than 220°C but greater than 100°C (Sulter, Kipyegon & Mutai, 2012). The geothermal fluids are used to heat a secondary fluid with a melting point less than 100°C with the help of a heat exchangers. Binary power plants make it possible to use low temperature geothermal fluids for power generation (Kabeyi & Olanrewaju, 2020).

### 3.1.4. Combination

These type of power plants use a combination of at least two of the basic technologies of power generation e.g. dry steam and flash, or flash and binary technologies. The combination depends on resource characteristics and costs involved (Kabeyi, 2019). The most economical long term scenario for is to develop a centralized plant instead of many small units (Long, Raman, & Harvey, 2012).

### 3.2. Central power plants

Central power plants involve drilling of multiple steam wells and interconnecting them with pipelines across the steam field to the common power plant (Kabeyi & Olanrewaju, 2020).

### 3.3. Wellhead Power plants

In wellhead technology, modular units of up to 15 MW are connected to a well or two with short steam pipelines as opposed to the long network of steam lines running across a steam field in the case of central plants (Kabeyi, 2020). The main elements of a Wellhead power plant consists of four main systems: Steam system (hot end), condensing system (cold end), turbine Generator set and electrical & control system. The plant consists of a turbine generator unit that operates on one single steam and condensing system. The figure 1 below shows the main components of a wellhead power plant.

![Figure1: A wellhead power plant Olkaria, Naivashia Kenya (Mendive & Green, 2012).](image)

From figure 1 above, it is noted that 5 wellhead units are assembled close to one another while maintaining the modularity and flexibility. Little field development in terms of pipe networks is observed while the plants remain small in size.

### 3.3.1. Comparison of central and wellhead plants
It is important to compare and contrast the central and wellhead plants in terms of the various important parameters as tabled in Table 1 below.

**Table 1: Comparison between geothermal central power plants and the wellhead generators (Kabeyi, 2020)**

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>CENTRAL POWER PLANT</th>
<th>WELLHEAD GENERATOR</th>
</tr>
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<tbody>
<tr>
<td>Set up period</td>
<td>Takes more than 2 years to set up</td>
<td>Takes between 3-6 months</td>
</tr>
<tr>
<td>Flexibility/Portability</td>
<td>Not flexible and can’t be moved from one site to another.</td>
<td>Are modular containerized plants that can easily be relocated and customized to alternative viable geothermal sites</td>
</tr>
<tr>
<td>Customization</td>
<td>Are not site specific and does not have to fit a specific requirement.</td>
<td>Are customized to fit the requirements of the specific wells they are fitted on.</td>
</tr>
<tr>
<td>Number of wells</td>
<td>Fed by multiple wells. Across a steam field</td>
<td>Operate on a single or just a few well.</td>
</tr>
<tr>
<td>Operating Efficiency</td>
<td>High</td>
<td>Low because the technology is in its developmental stages thus much is known it.</td>
</tr>
</tbody>
</table>

From table 1, it is noted that there are significant differences between central or conventional power plants and the wellhead power plants.

3.3.2. Examples of wellhead power plants

Several wellhead power plants are in operation on both temporary and permanent basis (Mendive & Green, 2012). These wellheads plants include:

i.) *Geothermal wellhead power plant in Naivasha, Kenya*

The Geothermal Development Associates (GDA) delivered this plant in June 2007. It is a non-condensing flash system with the advantage of simplicity, affordability and maximum portability of wellheads (Mendive & Green, 2012). This plant is a 2MW nominal geothermal steam turbine generator. It is located on the Oserian flower-growing facility and is owned by the Oserian Development Company.

ii.) *Wellhead at San Jacinto*

This plant operated between 2005 and 2012 in Nicaragua, generating 10 MW using a back pressure turbine from 150 tph steam as part of the original concept of a 72 MW of net capacity central power plant (Long, 2010; Long, Raman & Harvey, 2012).

iii.) *Eburru Wellhead power Station*

This power plant was commissioned in 2012 at a capacity of 2.52 MW by the Kenya Electricity Generating Company Ltd. It was designed, manufactured and installed by the GDA) in collaboration with KenGen engineers. In Kenya at Eburru some 11 km from Naivasha. It was the first wellhead power plant in commercial operation in Kenya and continues to operate today.

iv.) *Olkaria 5 MW Wellhead power plant*

These 5 MW power plant is owned by Kenya Electricity Generating Company and was assembled by the Green Energy Group (GEG) at Olkaria in Kenya.

4.0. Materials and Methods
A mixture of both qualitative and quantitative approaches was used in this study to collect data. These techniques included:

4.1. Observation

This technique involved systematic selection, watching and recording of the processes and systems in the wellhead power plant. Non-participant observation approach was applied for the installation, operation and maintenance of the wellhead generator plant and equipment at Eburru.

4.2. Document review / document studies

Document review involved examination of relevant existing documents with the aim of gathering information on a particular variables. Documents under review were hard copies and electronic copies which included; performance ratings, manufacturers manuals, maintenance schedules, publications, meeting minutes, newsletter and environmental assessment reports.

4.3. Interview

Data and information was collected by oral questioning of respondents and though telephone interview. In-depths interviews were conducted, while not limiting the respondents on scope provided the information was within geothermal energy exploitation experience. Questions asked were prepared in advance and then asked during a predetermined interview and the respondent(s).

4.4. Questionnaires

Open-ended questions were written and send to the correspondent, mainly engineers at Olkaria, via e-mail and responses sent via the same channel.

5. Results and discussions

Analysis of data collected through interviewing, observation, questionnaires and document review are done. One on one interviews were conducted with the engineers working on wellhead OW 43 and the findings noted down. Site visits were done on the 12th and 13th April 2017 where operation of wellhead OW 43 was observed together with verification of data collected. Questionnaires (2 sets) were admitted, the first to a senior engineer at Olkaria via email, and the second to the 3 engineers on ground at wellhead OW 43.

5.1. Technical Feasibility

These study sought to determine the technical feasibility or viability of wellhead generators really based on the performance indicators. This is in terms of their capacity, availability, breakdowns and maintenance and operational sustainability and reliability. Various technical issues on the application of the wellhead technology were observed and include; Heavy deposits of silt and algae forming at the bottom and walls of the cooling tower sump. Such deposits were thoroughly cleaned, as was the case during the inspection of OW 014 held on 27 January 2016. Another problem was the presence of heavy silica deposits in the A-plate perforations and perforated tube. This was managed by knocking off the deposits. Also chocking of the condenser cooling water inlet strainer was a problem. Ultimately, these technical challenges are not unique to geothermal wellhead power plants, and therefore cannot be used against wellhead technology as they are a result of the fluid characteristics and chemistry (Moses, 2019).

It was also noted that the availability of the station is about 77.7% to 92%, average load factor of 72.6, and capacity utilization of 81.1%. Whereas these parameters look inferior to the performance of central power plants, the values are well above other renewable like solar and wind.

5.2. Economic Feasibility

This study also sought to establish and analyze well head power plant costs and cash flow analyzing the costs and revenues from wellhead generators in a bid to determine whether their continued use made any financial sense.
Whereas more detailed financial data and information was not accessed, the researchers gathered sufficient data to use in making an informed opinion on the financial and economic performance of wellhead power plants. This section is based on sampled data from Olkaria and Eburru wellhead power plants. The study involved analysis of accessible financial records of Eburru and Olkaria wellhead power plants since inception in 2013 to the financial year ending June 2016. The graph figure 2 below shows the cumulative revenues.

Figure 2: Revenue for Olkaria and Eburru wellhead plants August 2012 to Feb 2017 (Kabeyi, 2020; Kabeyi & Olenwaraju, 2020)

From figure 2 above, the revenue from wellhead power plants steadily increased between 2012 and 2017 as a result of increased investment and continues improvement in generation and plant maintenance practices (Kabeyi, 2020).

The revenue and profits from wellhead power plants between the year 2013 and 2016 are presented in table 2 below.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Revenue (USD)</td>
<td>2,488,395.29</td>
<td>6,592,900.73</td>
<td>6,397,391.31</td>
</tr>
<tr>
<td>Annual budget expenditure</td>
<td>(201,312.52)</td>
<td>(134,655.18)</td>
<td>(429,085.93)</td>
</tr>
<tr>
<td>Profit before tax</td>
<td>2,287,082.77</td>
<td>6,458,245.55</td>
<td>5,968,305.38</td>
</tr>
<tr>
<td>Tax at 30%</td>
<td>(686,124.83)</td>
<td>(1,937,473.67)</td>
<td>(1,790,491.61)</td>
</tr>
<tr>
<td>Net profit</td>
<td>1,600,957.94</td>
<td>4,520,771.88</td>
<td>4,349,292.83</td>
</tr>
<tr>
<td>Rate of return</td>
<td>= NetProfit/Revenue * 100</td>
<td>= 64.3</td>
<td>= 68.6</td>
</tr>
</tbody>
</table>

From table 2, it is noted that the electricity revenue from the wellhead power plants grew steadily between 2013 and 2016, being the records reviewed. The net profit as a percentage of revenue in all cases was above 64% implying high profitability and low operation costs.

Businesses that are well managed show good performance in terms of profitability and value for investment. Above average business units are rare in all industries, which implies that wellhead power plants, present a unique business opportunity for investors (Barasa, 2018; Moses; 2020). Table 3 below shows computed payback for investment in wellhead power plants between 2013 and 2016.
Table 3: Payback Period (Authors calculation)

<table>
<thead>
<tr>
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<th>CASH FLOWS (USD)</th>
<th>CUMULATIVE (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial investment</td>
<td>16,518,580.00</td>
<td></td>
</tr>
<tr>
<td>2013/2014 Cash flows</td>
<td>1,600,957.94</td>
<td>(14,917,622.06)</td>
</tr>
<tr>
<td>2014/2015 Cash flows</td>
<td>4,520,771.88</td>
<td>(10,396,850.18)</td>
</tr>
<tr>
<td>2015/2016 Cash flows</td>
<td>4,177,813.77</td>
<td>(6,219,036.41)</td>
</tr>
<tr>
<td>2016/2017 Cash flows</td>
<td>4,349,292.83</td>
<td>(1,869,743.59)</td>
</tr>
<tr>
<td>2017/2018</td>
<td>4,349,292.83</td>
<td>(2,479,549.25)</td>
</tr>
</tbody>
</table>

Table 3 above shows cumulative cash inflows from wellhead power plants from the year 2013 to 2018. The value of payback can be computed as; Payback Period = \frac{1,869,743.59}{4,349,292.83} + 4 = 4.4 Years

The payback analysis for the wellhead power plants examined shows a payback period of 4.4 years. This is quite attractive and is another indicator of highly profitable and low capital investment opportunity.

5.3. Environmental Aspect of Wellhead Power plants

Geothermal energy is generally regarded as one of the most environmentally benign source of electricity generation. The environmental feasibility was carried out by analyzing independent environmental audit reports carried out by independent auditors. These audit reports numbered 104G5K-IEA-H-005, 104G5K-IEA-H-003, 104G5K-IEA-H-002 and 104G5K-IEA-H-001 were conducted by Howard Humphreys (East Africa) Limited for Kenya Electricity Generating Company Limited and submitted in December 2015. These audits were conducted in accordance to the Environmental Management and Coordination Act (EMCA) of 1999. The purpose of the audits is;

i.) Facilitate the management and control of environmental practices,
ii.) Assess the level of compliance with relevant statutory and regulatory requirements on development and environment,
iii.) Raise awareness of and commitment to environmental policy by development practitioners, the community and other concerned parties and finally maintain environmental health and safety standards, while continuously exploring opportunities for improvement.

5.3.1. Air emissions

Geothermal fields generally utilize underground water systems, with very little air emissions especially if using organic Rankine systems. Some concerns have been raised over radon release; although it is with limit in many places (PIRSA, 2009). The notable emissions created are in are construction related which is a feature common to many power plant projects regardless of technology. The fossil fuel related emissions like CO$_2$, SO$_2$, and NOx are not associated with geothermal power plant operations and if any as it may happen, can be minimized through technology like binary technology (Barasa & Magut, 2018). Emissions from geothermal are well specific and are same whether or not wellhead power plants are used.

5.3.2. Noise pollution

Geothermal power plants generate noise especially during exploration drilling and construction phases. During operation, wellhead power plants like Eburru produce noise during steam venting that happens whenever the plant trips. With direct-heat applications, noise is usually negligible during operation. Noise from normal operation of power plants generally comes from the cooling tower fans, steam ejector and turbine (Kabeyi, 2020). Although operating wellheads have been associated with Eburru, central power plants also face the challenge of steam venting.

5.3.3. Environmental impacts

The beauty of geothermal energy is that it is not associated with acid rain, mine related destruction and mine spoils, open pits, polluting oil spills, radio-active wastes, or damming of rivers due to geothermal energy utilization. However, conventional geothermal plants that harness hydrothermal reservoirs dominate the production of electricity from geothermal energy worldwide. The analysis identifies consumption of diesel for drilling and use of steel for wells casing and construction of the power plant as the main hot spots (Kabeyi, 2019; Paulillo, Striolo, & Lettieri, 2019). Lack of reinjection wells make wellhead plants to have a more negative environmental impact than central power plants (Kabeyi & Olanrewaju, 2020).
Calcite scaling in the wells and the high boron, chloride, barium concentration in the produced fluids are a major problem in a number of geothermal field to levels higher than safe limits (Barasa & Magut, 2018). Scaling is minimized by controlling wellhead pressures and by mechanically removing the deposits periodically. Silica scaling would be a potential problem were reinjection to be introduced.

Technically and economically, reinjection seems to be the most suitable option, and might also improve steam production (Kabeyi, 2020). This has a significant impact on the output of the power plant turbo generator, and on the performance of its condenser. Carbon dioxide is a major component non condensable gases in geothermal fluid. This can be extracted for economical use where the composition is high. For use in carbonated soft drinks manufacture. Thus, a potentially major environmental problem has been turned into a benefit (Barasa & Magut, 2018; Simsek, Yildir, & Gulgor, 2004). This however may be difficulty to implement where the stream field is developed with wellhead power plants.

5.3.4. Social impact

The wellhead power plants have both positive and negative impacts lie increased revenues to the government and the Kenya wildlife service thus enhancing conservation efforts. Creation of geothermal related tourism and increased grid power supply. Negative impacts include over speeding interference with wildlife habitat with brine discharge and noise as well as visual effect to the environment production which impact on human beings, wild animals and vegetation. Habitat loss due to the massive geothermal infrastructural installations is a common feature for both wellhead and central power plants. Invasion species, creation of noise, air and water pollution from such project have also led to ground instability resulting from project equipment vibrations. (Sutter, Kipyego & Mutai, 2012).

5.4. Discussion of results

According to Howard Humphreys (East Africa) limited, December 2015, major issues arose concerning the environmental management practices by KenGen at both Eburru and Olkaria. Firstly, was the issue of waste disposal. Here it was observed that KenGen did not segregate its waste leading to uncontrolled disposal of wastes. Corrective measures were suggested during the audits, which included; segregation of wastes at the source and the provision of clearly marked bins to facilitate segregation of the wastes into categories e.g. ordinary vs hazardous waste. This step has already been implemented as we witnessed during our visit on 12/04/2017.

From the generalized graph showing the revenues of the Eburru and Olkaria from August 2012 through to March 2017, we can observe a trend of increased revenues from the lows of 188,959.25 USD in August 2012 to highs of 3,668,845.32 USD in March 2017. This represents some 1836% increase in revenue over a period of 4 years 7 months. This growth has been attributed to, February 2012, OW 37 and Eburru were commissioned then the brake down for early 1 year in 2014(January - June) and 3.2 MW plants were installed. Considering the financial data specific to OW043 we can see that the plant has had an estimation average profitability of average profitability of above 65% for the financial years of between 2013 – 2014 to 2015 – 2016. These values are after charging a corporate tax of 30% and a payback period of 4.4 years compared to that of central power plant that is 10 years.

In evaluating technical feasibility, special attention was placed on availability of staff, their qualification, infrastructural problems and maintenance of the wellheads. It was observed that in reference to human capacity, which is properly skilled with the relevant degree qualifications. It was also observed that even at the specific wellhead power generation plants, most employees are technically trained, qualified and experienced in their responsibilities. Trainings are also conducted regularly in partnership with Green Energy Geothermal of Iceland, who are the suppliers of the wellhead generators used by KenGen. There sufficient capacity building was done to sustain operation and maintenance of wellhead power plants.

Wellhead plants like other plants face operational challenges and breakdown. The most common technical challenges at the station included:

i.) Frequent trips of power evacuation line which is connected to distribution network.
ii.) Brine valves seizure,
iii.) Turbine rotor failure,
iv.) Cooling tower fan breakdown and
v.) Compressor breakdown.
vi.) Silica deposit on moving parts, like turbine inlet valve positioners, thus the valves allowed stream into
the turbine prematurely.
vii.) Turbine rotor failures, brine valve seizures, cooling tower fan breakdowns and compressors breakdowns
have also been managed through regular maintenance carried out twice annually.

6. Conclusion

Wellhead technology is still new and its long term implications are still not established but for operating wellhead
power plants, short term viability is proven in terms of technical, financial and environmental feasibility. They are
inferior to centralized power plants in terms of most performance indicators. Wellhead power plants can ensure early
generation and reduce the long time wait to early power generation and cash flow and can substitute central power
plants where the steam field has wide variation in wellhead characteristics by optimizing generation for each well
separately.

In regards to economic and financial feasibility, this study found that wellhead technology is highly profitable with
net profit of over 65% for the plants studied. It was also observed that it’s computed payback period of about 4.4 years
is significantly lower than that of the central power plants of about 10 years. This makes the geothermal wellhead
technology highly attractive for investors. This study shows that the geothermal WHG technology is financial feasible
and hence attractive to investors and financiers.

The study further established that the major technical issues involve the connection to power distribution network
which subjects the power plant operations to highly variable consumer characteristics. Other challenges are equipment
related operation and maintenance issues like breakdown of the compressor, lack of redundancy of the compressor,
brine valve seizures due to particulate deposits of silica and turbine rotor failures. The study showed that the wellhead
power plants have early and quicker return on capital and are technically feasible in terms of operating load and
capacity factor which is lower than the conventional plants but still competitive compared to wind and solar. This
implies that wellhead power plants are viable as temporary plants and permanent plants but are inferior to central
power plants while long term viability needs further investigation.

7. Recommendations

Based on the findings of these study, the following recommendations are suggested;

i.) Since geothermal wellhead power plants have got some notable environmental and social impacts, it is
recommended that:

ii.) Education and awareness be carried out for local communities during project development phase on the
various impacts so that residents understand the danger and be encouraged to relocate to safer areas with
support of the project.

iii.) There is need for continuous monitoring of gases like H2S for timely reaction to avoid pollution and
related health hazards to workers and the neighboring community and ensure compliance within
environmental and health regulations and guidelines.

iv.) Unavoidable measurable damages like crop destruction witnessed in wellhead plants like Eburru due to
brine deposits should be compensated to mitigate losses to neighboring communities while early warning
to workers and neighbors should be done in case of anticipated environmental impact.

v.) For permanent use of wellhead technology plants, a reinjection wells and more efficient technology like
organic Rankine are recommended to increase generation efficiency and reduce environmental impact.

vi.) It is recommended that the management of the geothermal wellhead power plants be vigilant in
implementing the recommendation of the initial audit reports according to the given deadlines. It should
also work closely with National Environmental Management Authority (NEMA) and Kenya Wildlife
Services (KWS) to ensure that they are always in compliance with the relevant legislations. Regular
maintenance should also be done as at when scheduled at all times to avoid breakdowns.

vii.) The financial viability of wellhead power plants will be increased if governments provide tax incentives
like reduced or zero corporate tax from the revenue.
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