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Geothermal Power, A Viable Mini-Grid Solution for Rural Electrification in Tanzania. A Case Study of Kisaki Village

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ABSTRACT

Despite registered strides made in rural electrification programmes primarily through traditional grid extension approach, findings show that only 17% of the rural population (38 million) had access to modern and sustainable energy services. The rural electrification progress has remained very slow due to the remoteness of many villages, high cost of connections due to the low population densities ad complicated terrain which makes the extension of centralised grid system uneconomical and hard to implement. To meet the energy demand, the off-grid communities utilise costly and non-environmentally friendly energy sources such as kerosene fuel (for lighting), diesel generators (for productive works and lighting) and biomass (for cooking). All of these alternatives pose reliability, adequacy and environmental challenges in the provision of energy services in the rural areas. The isolated mini-grids technology that generates electricity through tapping into locally available renewable fuels resources and distribution networks. As the mini-grids built and operated near the electric loads required to serve, help to lessen the need for the construction of costly high voltage transmission lines and hence increases the resilience of grids to both natural disasters and cyber-attacks. Geothermal energy can leverage its geographical development barrier of being located in remote areas to generate it's uniquely reliable, affordable, and environmentally sound baseload power to meet the demand of these isolated communities. The existence of proven, robust, mature technology, enabling policies and regulatory framework can improve the commercial viability and adoption of isolated mini-grids utilising low-enthalpy geothermal resources for small-scale power generation and distribution hence playing an important role in accelerating access to modern electricity to the rural communities in Tanzania, particularly those closer to undeveloped but commercially viable hydrothermal resource and hence helps to unlock the inclusive growth in remote rural areas. Tanzania is categorised as a regional leader in mini-grid development in East Africa, deployment of geothermal mini-grid systems can leverage heavily on the lessons learnt from other renewable energy technologies with feasible business models. Kisaki geothermal prospect with a thermal spring of a maximum surface temperature of 72.3°C, located more than 200 kilometres from the central grid presents a good case for this study. Upon confirmation of geothermal resources through test drilling, electricity can be deployed in a relatively swift manner via small-scale Organic Rankine Cycle binary power plant and distribution lines typically operating below 11 kilovolts to Kisaki communities that would otherwise have to wait for a lengthy period for a grid connection.

1. INTRODUCTION

The reliable and affordable electricity is a fundamental building block in both economic and socio-political advancement for any community irrespective of the location in the country. Access to modern and sustainable energy services is pre-requisite for both economic activity and human development as well as for water supply, health care, education, and recreational activities. Continued economic and population growth create strong demand for electricity, MEM (2014) estimated annual demand for electricity growing on average between 10 per cent and 15 per cent per annum, however the rate of access to electricity in most part of the country has not kept pace with the ever-increasing population growth in both rural and urban population. As of 2017, approximately 67% of Tanzania's population of around 57 million lived in rural areas which translates to 38 million. Over 17% of the rural population had access to electricity through the national grid, mini-grids or a household system. In rural areas, of the electrified households, over 34% were connected to the grid while off-grid solar powered nearly 65% of the households IRENA (2018). Despite these registered strides made in rural electrification programmes mainly through centralized grid extension paradigm, the majority Tanzanians who reside in rural areas still lack access to modern and sustainable energy services, this leads to their exclusion to their effective participation in income-generating activities.

The traditional grid extension approach is economically constrained in terms of geography and technology, the power networks extension has demonstrated to be a cost-competitive approach only for the region with a dense population which encompasses a sufficient load density potential to justify the high investment and maintenance cost of grid infrastructure systems while challenging and costly in the rural isolated communities as the settlements are distant from a grid, not sufficiently concentrated and clustered. ARE (2011) estimated per kilometre investment cost for transmission lines and distribution lines to be 22,750 EUR and 12,000 EUR respectively. Therefore, the rural electrification process is only possible when the government bears the costs for the extension of national grids to the rural areas. In numerous cases, competing demands on government funds make the state-owned national utility or a rural electrification agency lacks the resources to finance the additional power generation capacity and centralized grid extensions to remote areas of the country, where low levels of electricity consumption and limited ability to pay for service often make these extensions economically infeasible Tenenbaum et al (2014).

The situation, therefore, requires new innovative ways to deploy modern energy service in an affordable, reliable and timely manner in rural communities. The recent radical technological innovations and improvement made the utilization of the decentralized renewable power generation and distribution systems possible through mini-grids technologies. The decentralized system generates electricity using small-scale plants located near the electric loads required to serve. The mini-grids deployment model, therefore, helps to lessen the need for the construction of costly high voltage transmission lines, distribution line and increasing the resilience of grids to both natural disasters and cyber-attacks. The acceleration of mini-grid deployment can play an important role for meeting the ever-growing energy needs particularly in the rural areas where central grid extension is uneconomical. IEA (2014) estimated that electricity from the mini-grids and stand-alone off-grid systems will play key roles in extending electricity and serve an estimated

140 million of the projected 315 million rural Africans who currently don't have access to national grids electricity by 2040 if 100,000–200,000 new mini-grids are built. This translates to 4,000 to 8,000 mini-grids deployment per year through 2040. In the Tanzania rural electrification investment prospectus, the country estimates that about half the rural population may be more cost-effectively served by decentralized options than by centralized grid expansion WRI (2017).

Geothermal energy can leverage its geographical development barrier of being located in remote areas to generate it's uniquely reliable, affordable, and environmentally sound baseload power to meet the demand of these isolated communities through mini-grid technology. The technical and engineering principles of small geothermal power plants, either binary or flash steam is well established with different advantages and challenges for each type of technology. The economics of the geothermal mini-grid can be attractive and sensitive to the presence of strong legislative support, regulation and licensing. Therefore, a combination of right and proven technology, appropriate enabling policies and regulatory framework improves the viability and adoption of low-enthalpy geothermal resources for decentralized small-scale power generation and distribution through mini-grid technology.

Geothermal power can play an important role in accelerating access to modern energy to the rural communities in Tanzania, particularly those located close to the undeveloped geothermal fields and hence helps to unlock the inclusive socioeconomic progress in remote rural areas. According to WRI (2017) report, Tanzania is mentioned as a regional leader in mini-grid development in East Africa, the breakthrough happened in 2008, the year when the country instituted a ground-breaking mini-grid policy and regulatory framework referred to as the Small Power Producers (SPPs) framework to encourage private sector investment in the sector. Since adoption, a total of more than 100 mini-grid systems are currently in operation by the national utility, private businesses, faith-based organizations and local communities. Technology-wise, hydro is the most common technology (49 mini-grids), 19 fossil fuel systems, 25 biomass mini-grids, and 13 solar mini-grids serving about 184,000 customers. There are to date no wind or geothermal mini-grids in Tanzania.

As no geothermal mini-grid currently exist in Tanzania, the deployment of the systems can leverage heavily on the lessons learnt from other renewable energy technologies with established feasible and effective business models. Upon confirmation of the existence, exact location, and potential of the geothermal reservoir in the potential fields through test drilling, electricity can be deployed in a relatively swift manner to the remote rural communities that would otherwise have to wait for a lengthy period for a grid connection. A short overview of the mini-grid technologies, geothermal power technologies, financial feasibility, policy, and regulatory framework and a case study area, Kisaki case study are covered in the next paragraphs.

2. MINI-GRID TECHNOLOGIES OVERVIEW AND DEPLOYMENT

RECP (2014) defined mini-grids as small-scale electricity generation (from 10 kW to 10 MW), and the distribution of electricity to a limited number of customers via a distribution grid that can operate in isolation from national electricity transmission networks and supply relatively concentrated settlements. Micro-grids are similar to mini-grids but operate at a smaller size and generation capacity (1-10 kW). In Tanzania, the mini-grid and micro-grids are referred to as the Small Power Producers (SPPs) of between 100 kW up to 10 MW and very small power producers (VSPPs) of between 15 kW and 100 kW respectively. In either case, the SPPs and VSPPs must satisfy both a size and a fuel or technology requirement as stipulated in the definitions above.

Mini-grids are frequently categorised according to who their customers are and whether or not they are connected to the main grid. The SPPs can also operate as combinations of these cases. Mini-grid may sell at wholesale to the national utility on the main grid but at the same time also sell at retail to households and businesses on new mini-grids that are electrically connected to the main grid but operate as separate distribution businesses Tenenbaum et al (2014). The four principal cases of classification are shown in Table 1.

Table 1: Four Basic types of mini-grid. Source: Tenenbaum et al (2014)

		Location of generation	
		Connected to isolated mini-grid	Connected to the main grid
Nature of customers	Selling retail (directly to final customers)	Case 1: Isolated SPP selling directly to retail customers	Case 3: SPP connected to the main grid selling directly to retail customers.
	Selling wholesale (to utility)	Case 2: Isolated SPP selling wholesale to utility	Case 4: SPP connected to the main grid selling wholesale to the utility.

A typical mini-grid has five basic features namely power generation, power storage, distribution, user or application subsystem and smart management systems. However, not all types of mini-grids require storage, for example, geothermal and hydropower systems usually run continuously hence no requirement of the storage system as opposed to solar and wind technologies. Of the five component, power generation constitutes a large share of the investment cost followed by the distribution networks and electronic equipment.

Mini-grid differs from other rural electric electrification solutions like grid extension and traditional energy sources for off-grid households stand-alone home system as provides the following five key value propositions to consumers and producers; 1) efficiency: lower energy intensity and distribution system loss 2) reliability: near 100 per cent uptime for critical loads 3) security: enable cybersecurity and physical security 4) quality: stable power to meet exacting consumer energy requirements 5) sustainability: expand generation to renewables and cleaner fuel sources.

The mini-grid deployment mechanisms and operation can be categorised into four main operator models being implemented in different parts of the world. The models include utility, private, community and hybrid. The principle and functionality differences between the models are based on the party covering the upfront cost, ownership of power generation and distribution assets, operation and maintenance of the system, and the relationships with customers RECP (2014). The model's implementation and successful deployment of each model depend on its unique contexts such as the natural environment (e.g. geography, energy resources and climate/weather conditions), the local socio-economic context, and the policy and regulatory environment. The funding depends on private equity and commercial loans as well as some form of government support, e.g. grants, subsidies, results-based financing, or public sector loan guarantees. The private operator model is often better suited (than utilities) to develop mini-grids where a private entity plans, builds, manages and operates the mini-grid system.

3. INSTITUTIONAL, POLICY, AND REGULATORY FRAMEWORK FOR MINI-GRIDS

The chapter examines the institutional, policy, legal and regulatory framework relevant to mini-grids deployment necessary for exploiting low-temperature geothermal systems for the off-grid communities' electrification programme.

3.1 The Institutional Framework

Tanzania mini-grid deployment is well constituted in the institutional framework and market structure of the Tanzanian electricity sector as illustrated in Figure 2. The framework consists of various key stakeholders in promoting, regulating, and operating mini-grids in the country MEM (2013). The stakeholders comprise of both national institutions, private-sector operators and nongovernmental organizations which strongly and strategically work together to realize the development and scale-up of renewable energy mini-grids technology.

Table 2 explains, in brief, the responsibilities of the key agencies in the country's power sector.

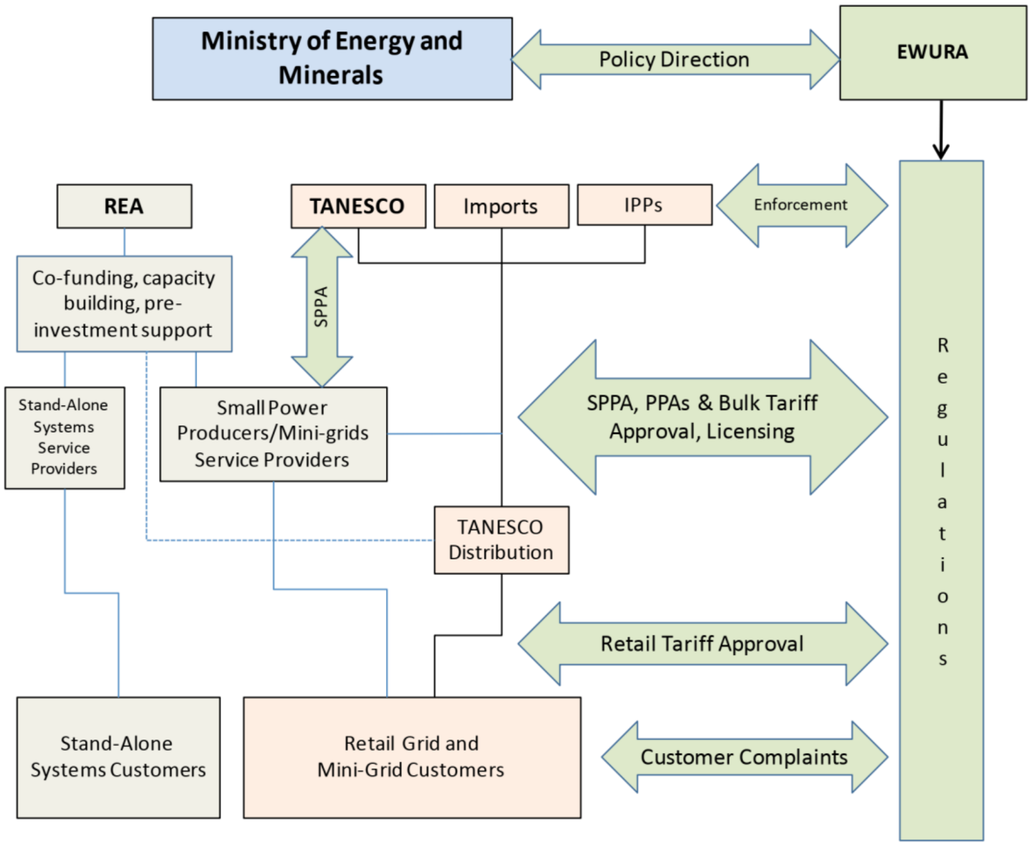

Figure 1: Mini-grid institutional framework. Source: MEM (2013)

Table 2: Overview of mini-grid institutional landscape in Tanzania (Source: Adapted from IRENA (2018))

	Topics	Institution	Description
Primary Measures	Planning	The Ministry of Energy (national planning) The Rural Energy Agency (rural areas)	The Rural Energy Agency manages the Rural Energy Fund, which provides grants to mini-grids and solar home systems as well as extensions of distribution lines. The Rural Energy Fund is funded by the government through an annual budgetary allocation, international development agencies and a levy on revenues from the generation of electricity.
	Policy	The Ministry of Energy	Issues laws and policies to guide Tanzania's energy sector and develops the country's Power System Master Plan.
	Regulation	The Energy and Water Utilities Regulatory Authority (EWURA)	Responsible for the technical and economic regulation of electricity, water, petroleum and natural gas. EWURA has regulated the mini-grid sector since 2009 through the Electricity (Development of Small Power Projects) Rules.
	Implementation	Tanzania Electric Supply Company Limited (TANESCO)	TANESCO is responsible for over 61% of the electricity generated in Tanzania. In addition to utility-scale generation capacity, the utility also operates 21 isolated mini-grids with a total capacity of 77 MW, all but one of which is powered by diesel.

	Quality standards	Tanzanian Bureau of Standards	The Small Power Producers Rules require that regulated mini-grids conform to relevant power sector standards, as enforced by EWURA. In late 2018 the bureau further developed technical standards for mini-grid generation and distribution networks.
Secondary Measures	Environmental and health protection	National Environment Management Council	Mini-grids are required to comply with environmental regulations that include a scoping report and terms of reference for a full environmental and social impact assessment to be submitted to the council. The council determines whether a full ESIA study is required.
	Tax and business registration	Tanzania Investment Center (TIC)	Registration with the TIC for incentives, the Tanzania Revenue Authority for tax registration and local government authorities for business licensing and registration.
	Land clearance	Village/local government	A land lease or right of occupancy certificate must be issued by the village/local government. In the case of generation projects on private land, a sales agreement has to be entered into between the developer and the owner of the piece of land.
	Building permit	Local government	A building permit for the powerhouse and other buildings must be issued by the local government (district or municipal council).
	Water basin approval	Regional Water Basin Office	For hydropower projects, water rights must be obtained from the Regional Water Basin Office overseeing the basin in which the project is sited.

3.2 Mini-grids policy and regulatory framework

In the combination of other key policies and legislation governing Tanzania's energy and renewable energy sectors, the country established the specific policy and regulatory framework to encourage private participation in small-scale power production and distribution using renewable energy resources. The framework has been developed pursuant to the Electricity Act, Cap 131 with aims to accelerate electricity access and promote the development and operation of small power projects among local and foreign private investors. Eligible small power projects are those of capacity ranging from 100 kW to 10 MW and utilizing renewable energy source, intended to supply commercial electricity to the national grid or isolated grid.

The framework intends to reduce negotiation time and cost and opens the possibility of implementing rural electrification projects EWURA (2019). The framework includes Standardized Power Purchase Agreement (SPPA) and Standardized Power Purchase Tariffs (SPPTs) which are applicable between the developer and the buyer. The SPPTs and SPPAs enable the developer/sponsor to determine whether the given tariff will be able to recoup its investment over the term of the power purchase agreement. Since its inception and adoption of the regulatory framework issued by EWURA in 2008, the guidelines for the development of small power projects has been four times successively revised and calibrated from the key lessons learnt from the implementation of this electrification option. The framework's original focus was primarily on grid-connected, customer-owned SPPs, and over time it expanded to address issues relating to mini-grids, including licensing, tariff setting, implications of main grid arrival and access to financing IRENA (2018).

The first version of the SPP framework put forth in 2008, allowed developers to sell directly to consumers at cost-reflective tariffs, and to sell electricity to TANESCO at the national utility's avoided cost (which includes high avoided cost for sales to TANESCO's diesel-powered mini-grids). Under the framework, feed-in tariffs were technology-neutral: no allowances were made for the different costs of different technologies. In 2015, the framework was revised and covered the development of hydro, biomass, wind, and solar energy projects with a capacity of 100 kW–10 MW. Renewable energy feed-in tariffs (REFITs) are applied to hydro, biomass, wind, and solar projects of 0.1–1 MW. A competitive bidding process is required for wind and solar projects of 1–10 MW (as it is anticipated the cost of the technologies to plummet due to the technological advancement). Under the 2019 Standardized Small Power Projects Tariff rule, EWURA sets technology-specific feed-in tariffs (applicable to both on-grid and off-grid) based on the size of the plant as shown in Table 3. These SPPTs for SPPs are reviewed after every three years.

Table 3: Approved SPPTs for SPPs (Source: Extract from the Order, 2019: standardized small power projects tariff)

Capacity	Mini hydro	Wind	Solar	Biomass	Bagasse
	USc/kWh	USc/kWh	USc/kWh	USc/kWh	USc/kWh
0.1 - 0.5MW	10.65	10.82	10.54	10.15	9.71
0.51 - 1 MW	9.90	9.95	9.84	9.34	9.09
1.01 - 5MW	8.95	9.42	9.24	8.64	8.56
5.01 - 10MW	7.83	8.88	8.34	7.60	7.55

Furthermore, the 2019 SPPTs for the isolated mini-grid, the tariffs for sale of electricity by VSPPs shall be approved by EWURA upon a receipt of a tariff application from a VSPP or on EWURA's own motion. The tariffs shall be computed based on various parameters pre-determined by EWURA as shown in Table 4.

Table 4: Key assumptions for determination of tariffs for VSPPs (Source: Extract from the Order, 2019: standardized small power projects tariff)

Item	Value
Installed Capacity	The energy produced shall not be more than the energy required to meet the demand for four years
Return on Equity	18.5%
Cost of Debt	Not more than 9.0%
Debt to Equity ratio	70:30
OPEX	Not more than 8% of CAPEX
Capacity factor:	
Micro/Mini-hydro	not less than 55%
Biomass	not less than 85%
Solar	not less than 23%
Wind	not less than 25%
Capacity degradation	0.5%
Depreciation method	Straight Line Method
Depreciation period	20 years

4. GEOTHERMAL MINI-GRID

4.1 Overview of geothermal energy, development and utilization

According to the available geoscientific data and technology, Tanzania has crudely estimated the potential of above 5,000 MWe of geothermal power (National Energy Policy, 2015). On the surface, geothermal energy is usually manifested by the presence of hot springs, fumaroles, steaming ground, altered ground among other geothermal signatures. In Tanzania, some of these manifestations are found in many areas of the country including Kisaki-Morogoro, where our study focuses. Most of these indications are located in the Tanzanian part of the longest Eastern African Rift System which has traversed the country in both eastern and western arms, that is to say, Tanzania is strategically located to utilise the available potential Kalimbia (2016).

Geothermal energy is proved to be renewable, affordable, reliable and environmentally benign electricity supply. Contrary to other power generation technologies, geothermal power plants operate at a consistent baseload power production level, twenty-four hours a day regardless of changing the weather, seasonal variation and climate change impacts and providing a uniquely reliable and continuous source of clean energy. As of July 2019, a total of 24 countries in the world generate electricity from geothermal resources with a total installed capacity of 14,900 MW ThinkGeoEnergy (2019) whereby Kenya is the only African country in the world top ten electricity producers.

4.2 Geothermal power technology

Initially, the sourcing geothermal energy was focused mostly around condensing superheated steam in high-temperature areas. As not all geothermal sites possess the right conditions for such a process, the primary source of geothermal power became wet steam or a water-steam mixture. Geothermal technologies have been developed far enough to utilize many low-temperature fields for power consumption, this is known as binary technology. In order to achieve the suitable inlet parameters to the turbine, the energy conversion system utilizes a secondary working fluid, often an organic fluid, with desirable thermodynamic properties. The working fluid (in a closed loop) receives heat from the geothermal fluid through a heat exchanger, expands through the turbine, goes through a condenser and lastly fed back to the heat exchangers using a feed pump.

Relatively low capital expenditures combined with short projects project implementations period provide incentives for the small-scale deployment of geothermal mini-grid. Kisaki being a low-temperature geothermal resource field of temperature 150°C or less, it becomes difficult and expensive, although not impossible, to build a conventional flash-steam plant that can efficiently and economically put such a resource to use. The fundamental reason for the latter is simply the thermodynamic difficulties in flashing the geothermal fluid to achieve substantial and economic inlet pressure for the turbine for conventional flashing technology. The other reason can be difficulties in attaining wells flow spontaneously at such lower temperatures, and if they do, there is a strong likelihood of calcium carbonate scaling in the well DiPippo (2016). The thermodynamic constraints on the generation technologies make a binary technology using Organic Rankine Cycle (ORC) or Kalina Cycle a feasible technology where the plant operates at temperatures range of 90 –150°C to provide electricity for the village depending on the established demand. The generated capacity can furthermore be scaled depending on the flow rate and fluid temperature of the reservoir.

The small-scale power plant design for the Kisaki geothermal field utilising the commonly used ORC can be illustrated in Figure 3.

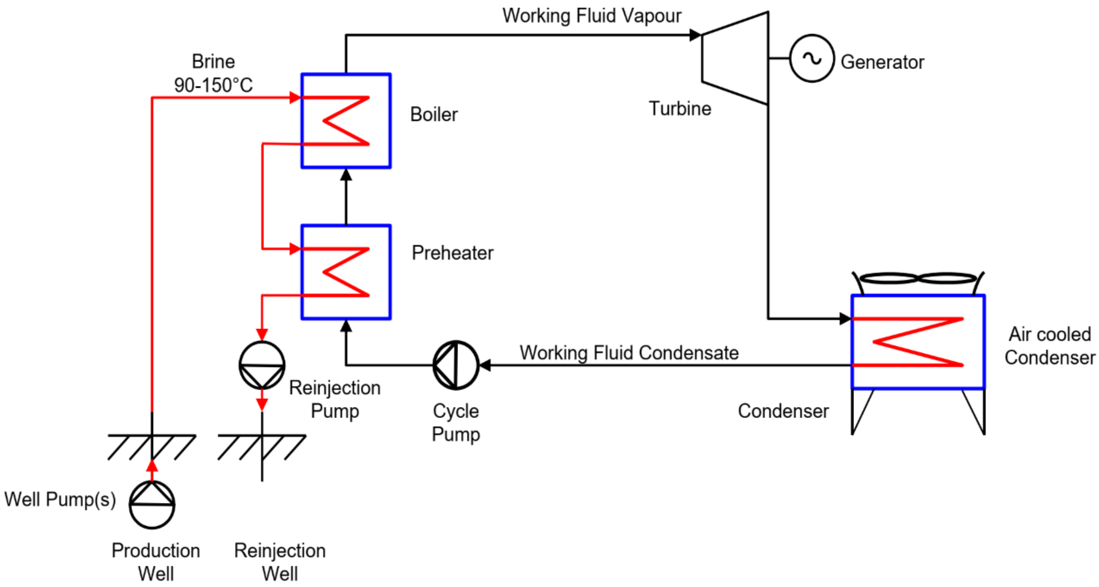

Figure 2: Simplified schematic of a basic binary geothermal power plant

4.3 Kisaki village, a case study area

Kisaki village is located in the south-west of Morogoro town. The village is accessible through 195 kilometres tarmac road from Dar es Salaam to Morogoro town, then 137 kilometres unpaved road to the village. The village can also be accessed by TAZARA railway line from Dar es Salaam to Kisaki railway station. The village population was estimated to be 16,763 (Kisaki village government, 2017) with an average of 5 people in the household. Just like most of the villages in Tanzania, Kisaki is not connected to electricity from the national grid. The closest distance to the grid is at the Morogoro town is more than 200 kilometres.

As no immediate or medium plan for grid extension, villagers seek all the possible forms and alternatives of energy sources to meet their energy demand. Diesel generators, kerosene, firewood and to a small extent solar PV are the main source of energy within the community. All sources above pause great social, economic and environmental concerns to the villagers. Despite providing power around the clock, diesel generators are expensive to run, characterised with volatile fuel price, noisy and smoky.

The generators are mostly used at night for powering homes and daytime for productive works i.e. welding, milling machines. Firewood is the second most consumed source of energy, 100% villagers depend lone on the charcoal to meet the cooking and heating demand, and this contributes to the highest degree of forest deforestation and degradation in the neighbouring forests and poses a significant threat to the environment. Putting it on large scale, it is estimated that a total area of 469,000 hectares of forest cleared each year (the majority on village land) in Tanzania and partly because of demand for biomass energy. Few villagers utilise mostly 5 Watts photovoltaic (PV) panel solar home system which is only capable to meet small-scale consumptions i.e. lighting at night and charging mobile phones. Most of the villagers find the system meagre and coupled with weak batteries which require constant replacement.

Five kilometres away from the centre of the Kisaki village exists a thermal spring with a surface temperature of 72.3°C. The hot springs well up from unconsolidated sediments JICA (2014). Upon confirmation of this geothermal resources through test drilling, electricity can be deployed in a relatively swift manner in the Kisaki rural communities that would otherwise have to wait for a lengthy period for a grid connection. Apart from electricity for domestic uses within households, geothermal being baseload source of generation enables to adequately supply reliable electricity for productive activities to support income-generating activities which the other renewable energy technology cannot meet. The load in Kisaki village can be estimated based on the following assumptions as shown in Table 5.

Table 5 : Kisaki village load estimates

S/n	Loads	Consumption(kWh)/use	Total Consumption (kWh)/day
1.	Domestic uses	0.28 for 3353 households	928
2.	Community uses	2,000	2,000
3.	Productive uses	1,000	1,000
Total consumption			**3,928**

The domestic load in the Kisaki village is roughly estimated from the country per capita electricity consumption of which was estimated to be 101 kWh per year MEM (2014), the village population of 16,763 and estimated 5 people per household in most rural villages in Tanzania NBS (2012). The productive uses including small-scale enterprises, agro-processing or small-scale industries estimated to consume 2,000 kWh per day and lastly the community use such as health centres, schools, churches and mosques estimated to consume 1,000 kWh/day. Therefore, the annual total village energy demand is estimated to be 1,433,613 4.16 kWh.

4.4 Geothermal mini-grid design

As previously covered, the geothermal mini-grid will comprise of small-scale binary cycle geothermal power plant, along with its cooling system for power generation, low to medium voltage distribution systems, user or application subsystem and smart management systems. The geothermal plant size and distribution systems are dictated on the amount of load required to meet the demand of the village. As geothermal power plants typically not equipped to follow system demand and are usually deployed to provide a baseload to the system, the combined size of a plant should not exceed the minimum system demand unless equipped with load tracking controls Gehringer and Loksha (2012). In this case, therefore, the plant size will be established as per established daily village demand which is affected by availability factor, capacity factor, equipment efficiencies and overall characteristics of the resource.

Various geothermal modular plant designs are available in the market, for the example, the Heat Power Climeon system which claims to operate in much low temperature and pressure conditions than the ORC with much higher efficiencies levels to generate electricity at a low temperature between 70-120 °C, low pressure of 2.5 bar(a) and 40 l/s of geothermal fluid flow. The Kisaki resource parameters of 100 °C temperature, 40 l/s of hot volume flow, the pressure of 2.5 bar (a) and the cooling of the temperature of 25 °C can utilise the Climeon 150 kW module to meet the demand.

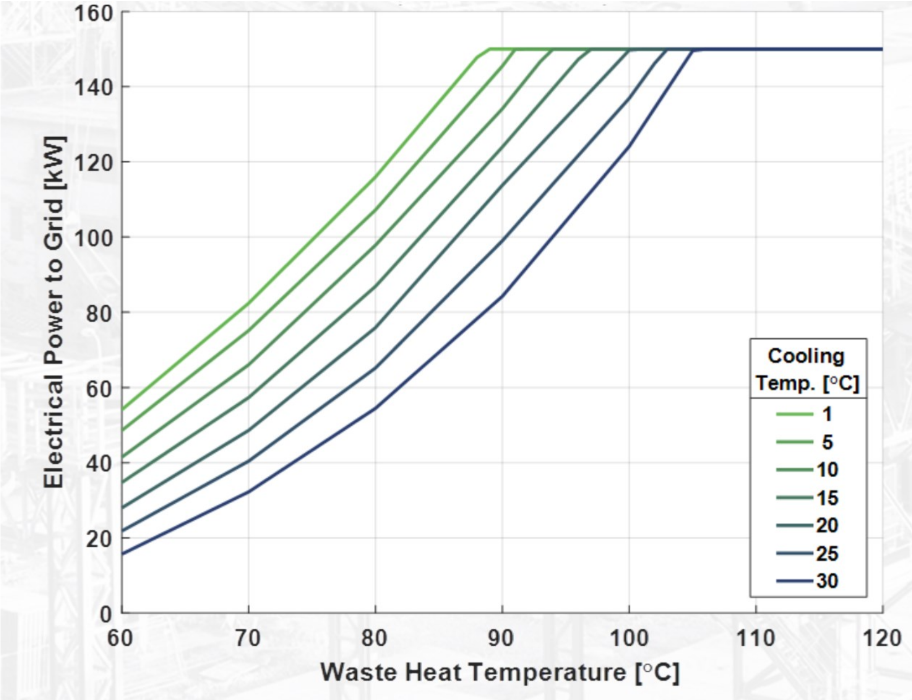

Figure 3: Modular units capacity with respect to resource and cooling temperatures (Source: Climeon)

The Kisaki village is approximately six square kilometres in the area which anticipates reducing transmission and distribution losses greatly as the distance to the load is quite small. The distribution system is anticipated to operating below 11 kilovolts (kV). The distribution stations can be in the two corners of the village and the load of the village will be split approximately evenly between each regional substation. Lastly assumed that due to the short distances required in the distribution of the electricity that the line losses will be negligible.

Although it is not further investigated in this paper, it is important to mention the necessity of information and communication technologies and their crucial role in the proposed grid design. Phasor Measurement Unit (PMU) information is important to ensure synchronism of the system. In addition to maintaining a stable system, correct operation of the system directly relies on production and load measurements to know whether to add load, add generation, or to be disconnected. This also requires PMU information from the generation station and each load substation to monitor the state of system components and relay data back to the central controlled.

4.5 Financial feasibility

In order to undertake financial and economic viability of the proposed electrification arrangement, the project assumptions are required to be established, this includes the project duration (planning and construction phase, and operating phases), financial assumptions, detailed resource and plant technical assumptions, capital expenditure (CAPEX) and operating expenditure (OPEX). These assumptions and costs estimates should be based on the geothermal resource characteristics, best international practices, the country's fiscal arrangements and incentives, and site-specific parameters.

The financial model is a must prepared instrument to determine project feasibility and approximate funding requirements. The model is prepared to quickly process a comprehensive list of input assumptions and scenarios and perform detailed financial and economic analysis for a project investment over its economic useful life to ascertain whether the expected future cash inflows of the project are sufficient to attract both lenders and project sponsors to invest in the project. The commonly used investment appraisal techniques that measure investment attractiveness and establishes project viability include; payback period, net present value, rate of return methods, financial ratio analysis and LCOE (for power projects).

The financial risk analysis is of paramount importance in the real-world project investment evaluation as only a few variables can be determined with relative confidence while other estimates used in the analysis are subject to substantial uncertainty. In order to incorporate the inherent risk associated with the input parameters and establish the expected reliable project's cash flows for project evaluation, three techniques are recommended to treating uncertainty; sensitivity analysis, scenario analysis and Monte Carlo simulation analysis.

5. CONCLUSION

Tanzania can utilise her vast geothermal resources for the sustainable small-scale power generation and distribution in the isolated communities through mini-grid technology as the traditional central grid extension demonstrates to be not a cost-effective electrification track. Geothermal power mini-grid deployment in Kisaki village in this paper demonstrated a strong viable case. Leveraging on her leadership and viable business models in the mini-grid development in East Africa, Tanzania is well-positioned to utilize the technology to swiftly supply reliable and affordable electricity to many areas in the country with similar low-temperature, commercially viable hydrothermal resources hence opening new possibilities for socio-economic progress.
Apart from the existence of commercial geothermal resource, the successful deployment of commercially viable mini-grid systems relies on the clear and credible policies and regulations, institutional frameworks, delivery models and financing, technological solutions, capacity building and cross-sector linkages factors. The Tanzania SPP framework provides mechanisms for the deployment of the mini-grid technology, however, the policy covers only hydro, biomass, wind, and solar energy projects with a capacity of 100 kW–10 MW, geothermal energy is not yet encompassed. From the established demand of the village and field geothermal resource characteristics, the mini-grid is designed and optimized to produce and distribute electricity to households, businesses and public institutions.

To further improve the economics of the electrification arrangement particularly for geothermal technology, the developer should seek the inclusion of the technology in the mini-grid framework to enjoy the financial incentives from the government. The incentives can be significant instruments to reduce the CAPEX (exploration drilling and distribution lines) and enhance the deployment of this technology.

REFERENCES

ARE .: Alliance for Rural Electrification (ARE) Mini-grid Policy Toolkit. webpage: https://ruralelec.org/publications/mini-grid-policy-toolkit, (2011).

DiPippo, R.: Geothermal power plants. Principles, applications, case studies and environmental impact .4th ed. Butterworth Heineman, UK, 772 pp. (2016).

EWURA .: Small Power Projects. webpage: https://www.ewura.go.tz/small-power-projects/, (2019).

Gehringer, M. and Loksha, V.: Geothermal handbook: planning and financing power generation. Energy Sector Management Assistance Program (ESMAP), technical report 0 02/12, 150 pp, (2012).

IEA .: Africa Energy Outlook: A Focus on Energy Prospects in Sub-Saharan Africa, Paris, (2014).

IRENA. : Policies And Regulations For Renewable Energy Mini-Grids, International Renewable Energy Agency, Abu Dhabi, 88 pp (2018).

JICA.: Data collection survey on geothermal energy development in East Africa - Final report Tanzania. JICA, website: open_jicareport.jica.go.jp/pdf/12147823.pdf, (2014).

Kalimbia, C.: Business Case of Ngozi Geothermal Power Project, Mbeya, SW-Tanzania. Report 9 in Geothermal training in Iceland 2016. UNU-GTP, Iceland, (2016).

MEM. : Investment Plan for Tanzania: Scaling Up Renewable Energy Programmes. Ministry of Energy and Minerals, Dar es Salaam, 146 pp, (2013).

MEM.: The electricity supply industry (ESI) reform strategy and roadmap ESI reform strategy and the roadmap. Ministry of Energy and Minerals, Dar es Salaam, 52 pp (2014).

National Bureau of Statistics.: PHC: Tanzania regional profiles. NBS, webpage: www.nbs.go.tz/nbs/takwimu/census2012/RegProfiles/12_Mbeya_Regional_Profile.zip, (2012).

RECP. : Renewable Energy Cooperation Programme for EU Energy Initiative Partnership Dialogue Facility. Mini-grid Policy Toolkit. Eschborn, Germany, 69 pp, (2014).

Tenenbaum, B., Greacen, C., Siyambalapitiya, T., and James, K.: From the Bottom Up: How Small Power Producers and Mini-Grids Can Deliver Electrification and Renewable Energy in Africa. Washington, DC: World Bank, 421, (2014).

ThinkGeoEnergy: Global geothermal capacity reaches 14,900 MW – new Top 10 ranking of geothermal countries: webpage: http://www.thinkgeoenergy.com/global-geothermal-capacity-reaches-14900-mw-new-top10-ranking/,(2019).

WRI. : World Resource Institute Report on Accelerating Mini-grid Deployment in Sub-Saharan Africa: Lessons from Tanzania, Washington DC, USA, 108 pp, (2017).