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Tanzania Geothermal Resources Development – Current Status

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ABSTRACT

Tanzania is developing a vibrant energy sector that is destined to support economic growth and improved quality of life of the people, as the country transforms into a middle income middle income and semi-industrialized economy by 2025. This goal can be realized if the sector can provide reliable, affordable, safe, and environment friendly modern energy services. The generation plan considers geothermal as one of the energy sources in diversified energy mix. The geothermal resource of Tanzania is estimated to exceed 5000MW, but it is not yet exploited for power generation except limited non-commercial direct use applications. In order to exploit to the country's enormous geothermal resources, the government has taken a number of steps including establishing a dedicated a company for geothermal development in 2013, developing domestic capacity in terms of human skills and equipment and improving enabling environment mainly streamlining of the legal and regulatory framework. The government has set a target of achieving at least 200 MW from geothermal by 2025. For achieving the target, four geothermal projects are being implemented and have reached test drilling phase to confirm the resource. This paper presents the current status of geothermal development in Tanzania, challenges and lessons learnt. In addition it presents the results of exploration studies, mobilization of funds and local capacity development as well as communities engagement prior to the planned test drilling.

1. INTRODUCTION

Tanzania is transforming its electricity energy sub-sector through diversification of energy sources and increasing the proportion of renewable energy including geothermal. It is anticipated that adding geothermal will not only increase energy access and sustainability but also will impact directly communities around the projects and ensure increased low carbon economic growth path. This will be realized through increased power generation and enhanced direct heat utilization in multi sectorial projects like agricultural, aquaculture, industrial, tourism, livestock and health. Such uses could include drying of crops, greenhouse farming, fish farming, animal husbandry, direct heat/cooling, space heating, and recreational facilities like swimming pools. This paper presents the current status, challenges and lessons learned the journey of developing the geothermal energy resources. Moreover, it presents important results of detail exploration studies, mobilization of funds and local capacity development as well as communities' engagement to implement geothermal projects.

1.1. Energy Sector Institutional set up in Tanzania

The Country's energy sector is divided into two main branches; the electricity and renewable energy and petroleum and gas sub-sectors. The key players in the electricity and renewable energy sub-sector include the Ministry of Energy (MoE), Tanzania Electric Supply Company Limited (TANESCO), Rural Energy Agency (REA), Energy and Water Utilities Regulatory Agency (EWURA), and Tanzania Geothermal Development Company Limited (TGDC). The institutional setup of the electricity and renewable energy sub-sector is as shown **Figure 1**.

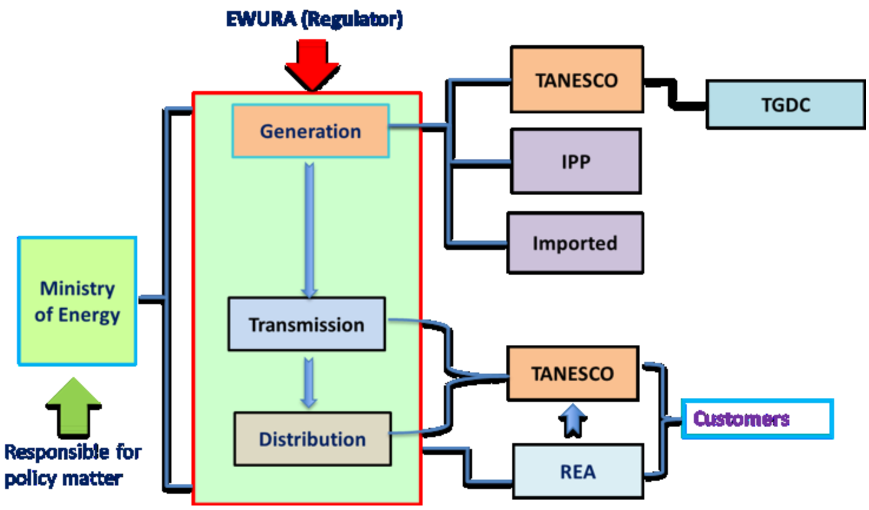

Figure 1: Institutional Set up of the Electricity and Renewable Energy Sub-Sector in Tanzania

The Ministry of Energy (MoE) is mandated with overall sector leadership and policy direction. It is responsible for formulation and monitoring implementation of energy policies for ensuring provision of secure, reliable, affordable, safe, efficient, cost-effective and environment friendly modern energy. TANESCO is the national power utility responsible for electricity generation, transmition, and distribution and is the main off-taker. TGDC is wholly owned by the government through TANESCO and is solely mandated with spearheading geothermal resources development in the country. Rural Energy Agency (REA) is responsible for the promotion of improved access to modern energy services in the rural areas. Energy and Water Utilities Regulatory Agency (EWURA) is responsible for technical and economic regulation of the electricity, petroleum, natural gas and water sectors. In addition to its generation, TANESCO buys electricity in bulk from Independent Producers (IPP) and from cross-border trade.

1.2. Current Situation of Electricity and Renewable Energy Sub-sector

The country's electricity generation mix consists of hydropower, natural gas and liquid fuel (HFO and diesel). As of May 2019, the total installed generation capacity for the grid system was 1,601.9 MW; grid installed capacity is 1565.7 MW and off-grid is 36.2 MW (MoE, May 2019). Hydropower accounts for 573.7 MW (36.6%), natural gas power plants contributes 892.7 MW (57.2%) and liquid fuel power plants is 88.8 MW (5.7%) , and biomass is 10.5 MW (0.6%) (**Figure 2**).

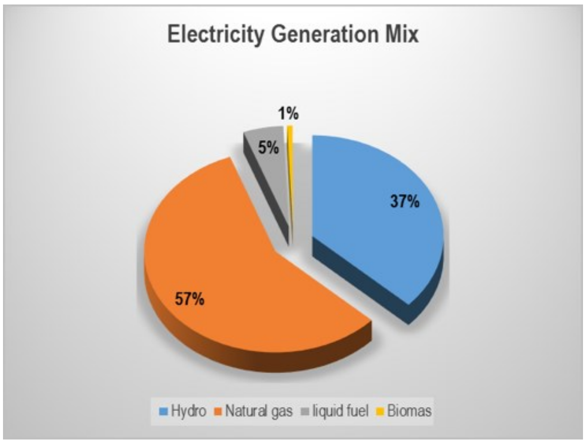

Figure 2: Electricity Generation Mix

According to the Power System Master Plan (PSMP, 2016 Update), electricity demand is growing at a pace of between 10% and 15% per annum and is forecasted to increase more due to growing energy requirements in transport, mining and industry sectors. Currently, there is no contribution from geothermal generation, however, geothermal energy is expected to contribute 200 MW to the national grid electricity target of 10,000 MW by 2025. The annual electricity consumption per capita is about 133 kWh, but the government vision is to become a middle income country by 2025 with electricity consumption of at least 490kWh/capita (PSMP, 2016).

2. GEOLOGICAL SETTING FOR GEOTHERMAL RESOURCES

Tanzania is among the countries that belong to the Eastern Africa Rift System (EARS), with significant geothermal potentials. Estimates using theoretical approach indicate a potential exceeding 5,000 MW but not yet exploited commercial use. Most of geothermal prospects have distinct surface manifestations, mainly hot springs. Exploration of geothermal started in 1976 and, to date, over 50 clusters of hot springs have been identified in the country occurring in diverse geological settings, which are divided in four zones as shown in **Figure 3**. The main the geological setting for the four zones that hosts geothermal resources in Tanzania are;

(i) **South-Western and Northern Volcanic Provinces:** comprises young volcanos situated along the EARS at the southern trip junction where the eastern and western branches converge. The Northern Province is located in the eastern branch of the EARS. The zones have huge potential of medium to high temperature geothermal systems that includes Ngozi, Songwe, Kasimulu, Kiejo- Mbaka, Eyasi, Natron, Manyara, and Meru.

(ii) **Coastal basin geothermal systems:** includes geothermal resources in Morogoro, Costal and Tanga regions. The occurrence is associate with coastal sedimentary basins, mainly fault hosted systems. Some of the geothermal prospects occurring in the coastal basins includes Kisaki, Tagalala, Mtende, Luhoi, Utete, Bombo, Kidugalo and Amboni.

(iii) **Intra-cratonic geothermal systems:** located in the Tanzanian craton which occur in the central part of the country and extend to the north to around Lake Victoria including those occurring in the intracratonic rift basins of the Tanzanian craton. They are likely fault hosted, low to medium temperature geothermal systems. Such prospects are Mponde, Takwa, Hika, Gonga, Msule, Isanja, Ibadakuli, Balangida, Kondoa, Balangidalalu, Mnanka, Nyamosi and Maji moto-Mara.

(iv) **Western rift geothermal systems:** occurring in the western branch of the EARS which is seismically. Some prominent features in the western rift includes Lake Tanganyika which is the deepest lake in Africa. Some of the geothermal prospects in this zone includes Mtagata, Maji moto-Rukwa, Mapu, Ivuna and Rock of Hades.

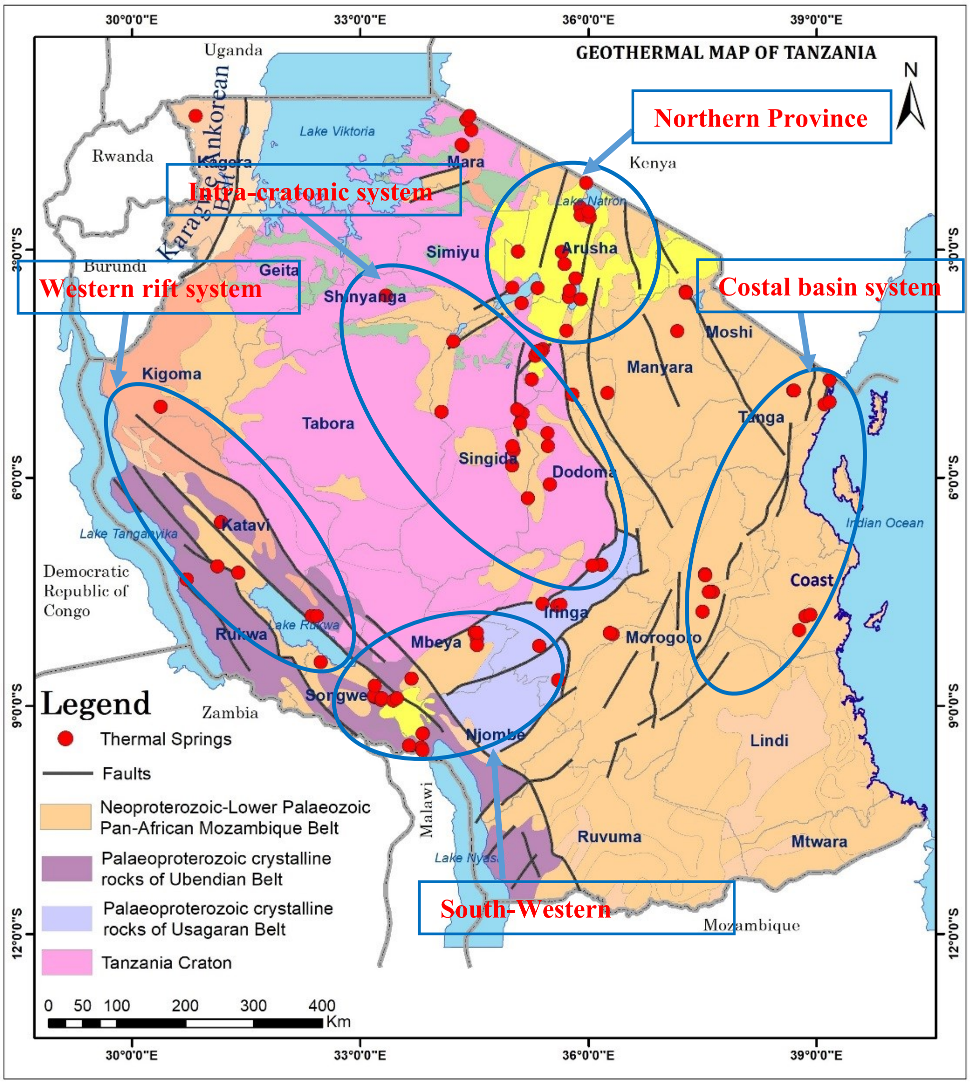

Figure 3: Tanzania Simple Geological Map Showing Geothermal Occurrence Zones.

3. GEOTHERMAL DEVELOPMENT IN TANZANIA

The government has set up short and long-term targets that has to be attained in 5 and 25 years respectively. The short-term target is to add 200 MW from geothermal resources to the national grid by 2025. TGDC is the government entity that is entrusted to make this happen. TGDC developed a Strategic Plan in 2017 that guides its business decision, processes and growth and realization of the national geothermal targets. The Strategy Plan targets are aligned with relevant government documents and plans among them being Power System Master Plan (2016 Update) and the National Energy Policy, 2015. The company is implementing four (4) flagship projects that have to be developed to achieve 200 MW by 2025. These projects are Ngozi, Songwe, Kiejo-Mbaka and Luhoi. In addition to selection of the flagship projects, Tanzania has prioritized three mainly strategic focus areas to ensure sustained geothermal development in Tanzania. These are (i) establishing enabling business environment for geothermal development through formulation of legal and regulatory framework, (ii) strengthening local technical capability and (iii) improving research and development of the geothermal sector.

The four (4) flagship projects have reached a resource confirmation stage through test drilling which is planned to be executed between 2018 and 2021. The following sub-sections presents important results of the surface exploration studies, development strategies and current status of each project;

3.1. Ngozi Geothermal Prospect

Ngozi geothermal prospect is located within the Rungwe Volcanic Province (RVP), southwest Tanzania, at triple rift intersection of the Western, Eastern and Southern Branches of the East African Rift System. It has been explored (geologically, geophysical and geochemically) since 1950's (GST, 1958 and Harkin, 1960, DECON, 2005). TGDC with technical support from UNEP/ARGEO and MFA/ICEIDA has carried out studies in the area with the intention of defining the geothermal system model from the previous existing models from different geo-scientific works and selecting drilling targets to confirm the resource potential and characteristics. The study was concluded in September 2016 and showed that the geothermal reservoir is beneath Ngozi with estimated temperature of 232 ± 13 °C, TDS of 15,800 ± 2300 mg/kg (Na-Cl composition), and a PCO2 of 15 ± 4 bar.

Geologically, the Ngozi is the major eruptive centre of the Rungwe Volcanic Province (RVP), characterized by young volcanic deposits of Plio-Pleistocene to Holocene age that are mainly composed of pyroclastics, basalts, phonolites and trachytes (Fontijn et al., 2012). The primary geothermal features are thermal water discharges (up to 89°C) at the bottom of the Ngozi Crater Lake. The heat source is likely a trachytic magma chamber, perhaps 5 to 7 km deep, which was replenished after the Ngozi Tuff eruption less than 1,000 years ago. The reservoir temperature is estimated at 232± 13ºC based on the observed outflow temperature on the lake bed of 89ºC (UNEP/ARGeo 2016). **Figure 4** is the possible conceptual model of Ngozi geothermal system.

The study further identified five (5) locations for test drilling around Ngozi; TGDC is planning to start with three (3) slim wells drilling in fiscal year 2019/2020. The Geothermal Risk Mitigation Facility (GRMF) has approved co-financing the drilling programme.

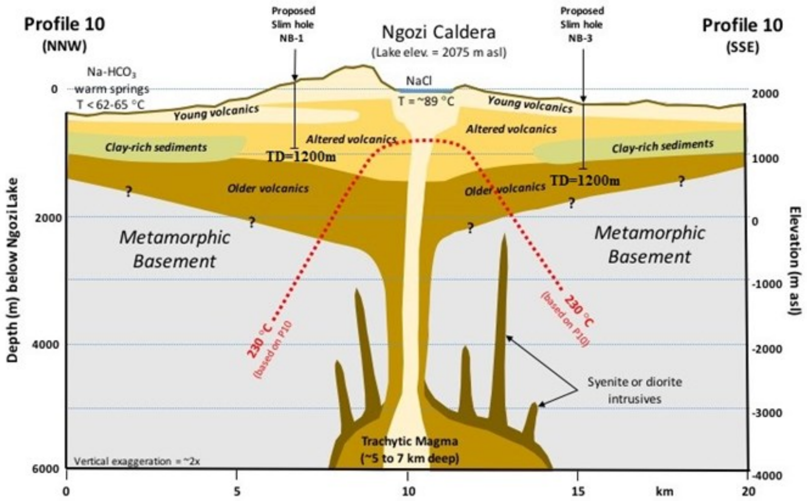

Figure 4: Conceptual model for Ngozi geothermal system.

3.2. Kiejo-Mbaka Geothermal Prospect

Kiejo-Mbaka geothermal prospect is located in the Southern part of the Rungwe Volcanic Province (RVP) which host Ngozi, Rungwe and Kiejo volcanoes in the south west of Tanzania, in Mbeya Region (**Figure 5**). Different studies have been undertaken in the prospect area either for geothermal assessment and/or for general geo-scientific academic researches. The most prominent studies include those by ELC, 2017, Ochman and Garofalo, 2013, Fontijn, et al., 2012, de Moor, et al., 2012, Delalande, et al., 2011 and Ebinger, et al., 1989. The study conducted by ELC (2017) concluded that Kiejo-Mbaka is a medium temperature geothermal system based on both water and gas geothermometric assessments with estimated reservoir temperature around 140 °C. Further, the system is manifested on the surface by hot springs which discharge in the areas of Kilambo, Kajala and Ilwalilo with temperature ranging 59 – 64 °C and are recharged by meteoric water as confirmed by the isotopic studies.

The study by ELC (2017) has recommend resource confirmation by test drilling and seven (7) possible locations have been identified. TGDC is planning to start with four wells (4), three of them being slim wells and one (1) full size well. The test well drilling programme is planned for in the fiscal year 2020/21. Funds mobilization from different sources for carrying out of test drilling is underway. The project has pass the GRMF grant support which will be co-financed together with Government funds.

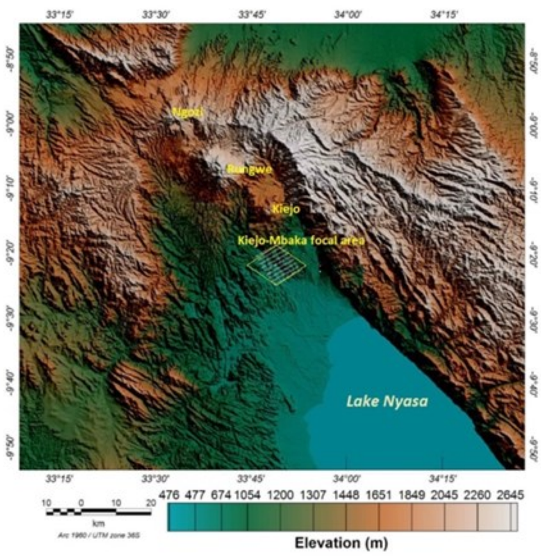

Figure 5: 3D topography view of Kiejo-Mbaka volcano in Rungwe Volcanic Province (RVP).

3.3. Songwe Geothermal Prospect

Songwe prospect is located in Songwe Region, just North West of Ngozi prospect. Detailed surface study for this prospect was completed in 2016 by UNEP/ARGeo technical consultants and was carried out together with Ngozi prospect. The study shows that Songwe is a low to medium temperature resource (112 ± 16 ^{0}C) more suitable for direct use applications and binary power plant. The study further recommended to undertake a gap filling study for Songwe prospect to determine appropriate locations and number of wells prior to embarking on test drilling.

TGDC in collaboration with East Africa Geothermal Facility (EAGER) carried out additional gap filling study in in the area between October, 2017 and June 2018. The study recommended Temperature Gradient Holes (TGH) drilling programme comprising fourteen (14) drilling locations to increase the knowledge about the system before undertaking actual test drilling programme for resource confirmation and suitability for direct use applications and power generation (**Figure 6**).

Pre-feasibility study for direct uses applications prospect was also conducted at Songwe prospect by TGDC in collaboration with EAGER. The study proposed a number of multi direct utilization mini projects such as aquaculture, drying agricultural crops, and recreational (tourism). With consideration that Songwe region is famous in agricultural activities like growing of coffee, pyrethrum, tea, beans and the like, TGDC believes that, introducing agri-processing technology such as drying of crops and fish farming to the farmers and developing tourism can have significant economic effect and benefits not only to the local community but also to the regional and national economy.

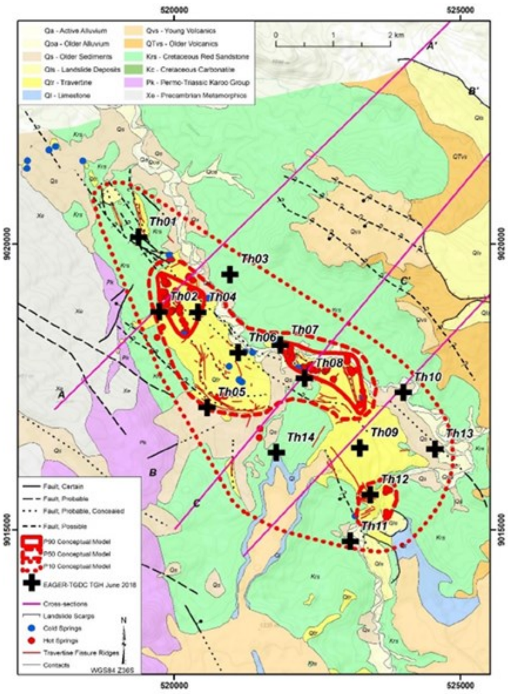

Figure 6: Map showing Songwe conceptual model and TGH locations.

3.4. Luhoi Geothermal Prospect

Luhoi geothermal prospect is located in Coast Region, about 150 km from Dar es Salaam. It is situated along the southern extension of the East African Rift System (EARS), “Coastal Basin”, which formed mainly in response to progressive fragmentation through time of the super continent of Gondwana. The detailed surface study was finalized by a consultant (ELC 2017) from Italy in 2017 in the joint project framework with Kiejo-Mbaka under technical support from the MFA Iceland/ ICEIDA. The results from the technical report show that Luhoi geothermal prospect host a low temperature geothermal system (95-145°C) and is suitable for direct uses and power generation using binary technology.

Geologically, Luhoi is located on the southern extension of the EARS in the south eastern coastal basin of Tanzania which split into the NNE-SSW trending Selous sub-basin and NNW-SSE trending Mandawa sub-basin where the two are separated by a spur of Pre-Cambrian basement (**Figure 7**). The prospect area occurs the northern intersection of the two sub-basins within Rufiji trough. This is the E-W trending basin which is covered by the sedimentary sequence which become thicker and younger toward the Indian Ocean in the east. The coastal basin of Tanzania was formed in response to progressive fragmentation of Gondwana where a series tensional regime and spreading events split the continental crust creating sedimentary basins along the eastern coast of the continent. The prospect is manifested by several hot springs (about 72 °C and 20-30 l/s flow) along the Luhoi River over a stretch of about 600 m and large amounts of accumulated travertine.

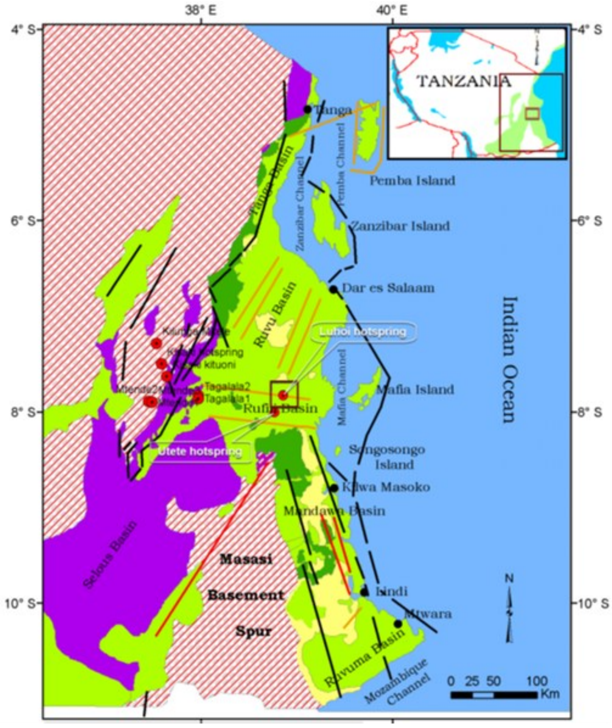

Figure 7: Luhoi geological map

4. DISCUSSION AND CONCLUSION

Geothermal development in Tanzania is currently at resources confirmation stage after registered its four (4) flagship prospects (Ngozi, Songwe, Kiejo-Mbaka and Luhoi) in the stage. The resources confirmation will be conducted through drilling programmes of a number of different test wells at particular prospects. The drillings programmes are set for implementation starting with three (3) slim wells drilling programme at Ngozi prospect during the financial year 2019/20 of which its preparations have been underway since 2018. TGDC plan is to complete the resources confirmations of its four prospects by 2022 all pave a way for the next stage of resources development. A fist MW from geothermal in Tanzania is expected in the 2022 from Ngozi prospect if the confirmed resource will be viable for power generation. This would be by using well head generators connected directly to the wells drilled.

Several initiatives to develop direct uses projects have been taken such as conducting regional and specific direct uses surveys. Such surveys conducted in Mbeya, Songwe, Coast, Morogoro and Shinyanga regions to identify possible opportunities for direct uses. Site specific surveys have been conducted in Ngozi, Songwe Luhoi, Ibadakuli, Kiejo-Mbaka and Kisaki. The identified opportunities include agricultural uses, industrial uses, recreational and geo-tourism. Specifically, the agricultural uses may include greenhouse farming, drying of crops, aquaculture, and chicken hatching.

Government efforts are ongoing in creating enabling environment for geothermal development through formulation of legal and regulatory framework which is expecting to encourage the development of the geothermal resources for power and direct uses projects. The draft bill for regulatory framework and institutional set up have already been prepared and completed in 2017. The draft bill is expected to address the challenges surrounding geothermal development in the country including current resources ownership and licensing regulatory mechanism.

Adequate resources capabilities in terms of human capacity, equipment and financial resources to undertake the upstream activities remain as main challenge encountered the development of geothermal. A number of measures are taken to overcome the challenges such as seeking training opportunities for staffs and experts from the government institutions that are involved directly and indirectly in developing and managing the geothermal industry. Trainings includes those of short, medium and long trainings, technical professional and soft skills training.

ACKNOWLEDGMENTS

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (Biomass)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2019			981.5	8,598	574	5,026			11	92	1,566	13,716
Under construction in December 2019			425	3,723	2115	18,527					2,540	22,250
Funds committed, but not yet under construction in December 2019			694	6,079	1011.8	8,863					1,706	14,943
Estimated total projected use by 2020			**1,976**	**17,310**	**3,696**	**32,375**			**11**	**92**	**5,688**	**49,824**

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2019

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Electrical installed capacity in 2019

4) Electrical capacity actually up and running in 2019

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1]	Type of Unit[2]	Total Installed Capacity MWe[3]	Total Running Capacity MWe[4]	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
Total									

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (other than heat pumps)

1) I = Industrial process heat — H = Individual space heating (other than heat pumps)
C = Air conditioning (cooling) — D = District heating (other than heat pumps)
A = Agricultural drying (grain, fruit, vegetables) — B = Bathing and swimming (including balneology)
F = Fish farming — G = Greenhouse and soil heating
K = Animal farming — O = Other (please specify by footnote)
S = Snow melting

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less,
since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5)]

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the cooling
rejected to the ground in the cooling mode as this reduces the effect of global warming.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

3) Report the COP = (output thermal energy/input energy of compressor) for your climate - typically 3 to 4
4) Report the equivalent full load operating hours per year, or = capacity factor x 8760
5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr
6) Cooling energy = rated output energy (kJ/hr) x [(EER - 1)/EER] x equivalent full load hours/yr

Note: please report all numbers to three significant figures
Due to room limitation, locality can be by regions within the country.

Locality	Ground or Water Temp. (°C)[1)]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2)]	COP[3)]	Heating Equivalent Full Load Hr/Year[4)]	Thermal Energy Used[5)] (TJ/yr)	Cooling Energy[6)] (TJ/yr)

TABLE 5.	SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2019

[1] Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

[2] Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

[3] Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^{6} W)
not operate at 100% capacity all year

[4] Other than heat pumps
[5] Includes drying or dehydration of grains, fruits and vegetables
[6] Excludes agricultural drying and dehydration
[7] Includes balneology

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]			
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps			
TOTAL			

TABLE 6.	WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 31, 2019 (excluding heat pump wells)

[1] Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)					
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total						

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	20					0
2016	23					
2017	25					
2018	26					
2019	30					
Total	30					

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$

Period	Research & Development Incl.	Field Development Including Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999						
2000-2004						
2005-2009						
2010-2014						
2015-2019	2					