TECHNICAL ASSISTANCE TO IDENTIFY THE MOST SUITABLE DIRECT USE APPLICATIONS AND TECHNOLOGIES IN LOW-TO-MEDIUM TEMPERATURE GEOTHERMAL SYSTEMS IN SIX AFRICAN COUNTRIES

CTCN REQUEST REF: 2019000050

DELIVERABLE #2: FIRST PROGRESS REPORT

DECEMBER 2020

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ABBREVIATIONS & ACRONYMS

AFD	Agence Française de Développement
AfDB	African Development Bank
BRGM	Bureau de Recherches Géologiques et Minières (France)
CERD	Centre d'Étude et de Recherche de Djibouti
CRIRSCO	Committee for Mineral Reserves International Reporting Standards
CTCN	Climate Technology Center and Network
DFID	Department for International Development (UK)
EAGER	East Africa Geothermal Energy Facility
EARS	East African Rift System
EDCL	Rwanda Energy Development Corporation Limited
EEPCo	Ethiopia Electric Power Company
ESMAP	Energy Sector Management Assistance Program (World Bank)
GDC	Geothermal Development Company (Kenya)
IESE	Institute of Earth Science and Engineering (New Zealand)
IPP	Independent Power Producer
JICA	Japan International Cooperation Agency
JICS	Japan International Cooperation Systems
KenGen	Kenya Electricity Generating Company Limited
Km	Kilometer
Masl	Meters above sea level
MEMD	Uganda Ministry of Energy and Mineral Development
MT	Magnetotelluric
MW	Megawatt
NDE	National Designated Entity
ODDEG	Office Djiboutien de Développement de l'Énergie Géothermique
OFID	OPEC Fund for International Development
ORC	Organic Rankine Cycle
TEM/TDEM	Transient electromagnetics/time-domain electromagnetics
TGDC	Tanzania Geothermal Development Company
UN	United Nations
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFC	United Nations Framework Classification
VES	Vertical Electronical Sounding

ACKNOWLEDGEMENTS

GreenMax Capital Advisors would like to thank the Climate Technology Center and Network (CTCN) management team, including Giulia Ferrini, Rajiv Garg, Elizabeth Mwangi, and Dr. Meseret Teklemariam Zemedkun for their leadership and guidance.

We would especially like to thank the UN National Designated Entities (NDEs) for Djibouti (Idriss Ismael Nour), Ethiopia (Yamelakesira Tamene Bekele), Kenya (Kelvin Khisa), Rwanda (Faustin Munyazikwiye), Tanzania (Gerald Majella Kafuku) and Uganda (Maxwell Otim Onapa), and the Project Proponents in each country: Djibouti Geothermal Energy Development Authority (ODDEG); Ethiopian Ministry of Mines and Petroleum, Geothermal Resources Directorate; KenGen Geothermal Development Division; Rwanda Energy Development Corporation Limited (EDCL); Tanzania Geothermal Development Company Limited (TGDC); and the Ugandan Ministry of Energy and Mineral Development (MEMD) for their support.

In addition, we would like to acknowledge all the local industry stakeholders and community representatives for their contributions to this study. This report would not have been possible without the support of these individuals and organizations.

INTRODUCTION

A. Context for the Assignment

To date, the main focus of utilizing geothermal resources in East Africa has been for power generation, as this technology offers a clean source of baseload power that reduces emissions and improves energy security. However, there is also significant untapped potential for direct use applications of geothermal energy, particularly in the agricultural sector, which is a key driver of economic activity across the region. In this context, the objective of this assignment is to provide specialized technical assistance (TA) services to the Climate Technology Center and Network (CTCN) in order to identify potential geothermal direct use applications in six East African countries – Djibouti, Ethiopia, Kenya, Rwanda, Tanzania and Uganda. The services aim to inform policymakers in each country to improve their understanding of opportunities for direct use geothermal projects from technical, financial and market viability perspectives. The TA will be provided to the CTCN National Designated Entity (NDE) in each country, along with Project Proponents:

- Djibouti Geothermal Energy Development Authority (Office Djiboutien de Développement de l'Énergie Géothermique, ODDEG)
- Ethiopian Ministry of Mines and Petroleum, Geothermal Resources Directorate
- Kenya Electricity Generating Company PLC (KenGen), Geothermal Development Division
- Rwanda Energy Development Corporation Limited (EDCL)
- Tanzania Geothermal Development Company Limited (TGDC)
- Uganda Ministry of Energy and Mineral Development (MEMD)

In each country, the TA aims to identify potential direct use geothermal applications as well as the corresponding sectors and technologies that are best suited to benefit from the utilization of direct use geothermal projects. The TA will also establish the economic and market viability of the identified direct use projects. In addition to supporting rural livelihoods and economic development, this project will also support each country's efforts to advance its climate commitments given the impact of geothermal development on energy sector decarbonization.

B. First Progress Report (Deliverable #2)

Section I of this report presents the methodology utilized for geothermal direct use site selection. **Section II** is a comprehensive review and analysis of existing data on low to medium temperature geothermal resources in each country, including gaps in the data. **Section III** provides a summary of the stakeholder consultations that were undertaken in each country, including which stakeholders were identified and engaged and what they were able to contribute to the study. **Section IV** presents information on the identified local communities that will benefit from the proposed geothermal direct use applications, including a categorization of possible opportunities for direct use projects.

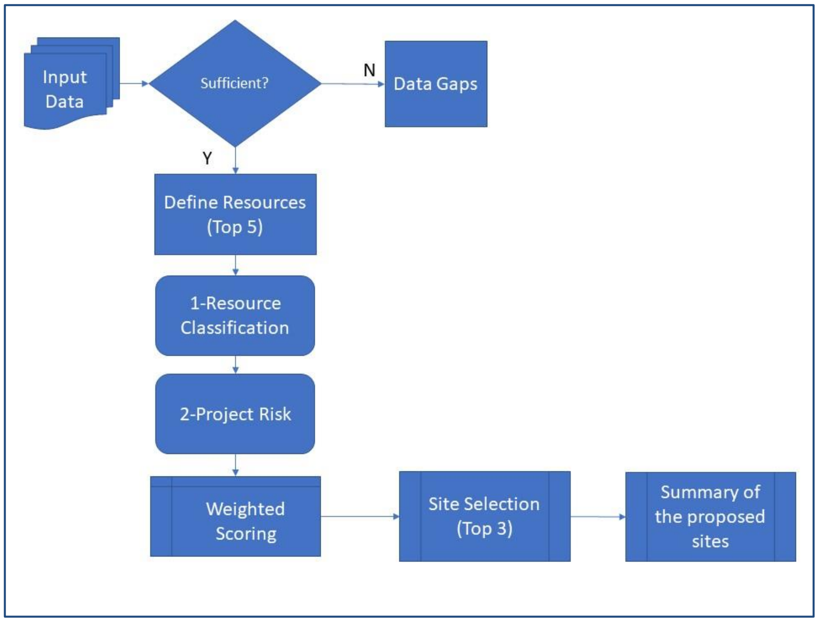
NB: Due to the limited nature of the scope of work, as well as other constraints on international and domestic travel associated with the global COVID-19 pandemic, the findings in this report should only be considered a **pre-feasibility study**. The data presented in this report is intended to provide a baseline for future research and more comprehensive/technical feasibility studies.

I. METHODOLOGY FOR GEOTHERMAL DIRECT USE SITE SELECTION

This section presents an overview of the methodology utilized for the selection of geothermal direct use sites in each country. As an initial step, primary source documents (feasibility studies, technical reports etc.) were provided by the Project Proponents in each country and where applicable, additional publicly available information was obtained through supplemental desk research. The amount of data/information available varied widely by country; some of the reports/studies provided were at the pre-survey phase, while others were at a more advanced stage (e.g. operation).

In general, there was an overall lack of data focusing specifically of low to medium enthalpy geothermal resources. Most of the studies undertaken to date have analyzed high enthalpy sites utilized for power generation rather than for direct use applications. To account for this and broaden the scope of the assessment, cascading systems – where the effluent from a power plant can feed a direct use application before it is reinjected or disposed of – were also analyzed. **Figure 1** shows the steps that were followed in the data analysis and site selection methodology. Gaps in existing/available data are summarized in **Section II** of this report by country; if the existing/available data was deemed sufficient, the identified geothermal resources were analyzed according to the site selection methodology outlined below. For each country, a combination of available data and local expertise was used to identify and analyze three of the most promising resources.

Figure 1: Data Analysis and Site Selection Approach



Source: GreenMax Capital Advisors analysis

In order to account for inconsistencies in the data across and within countries, a two-phase assessment of the information was developed. The first phase of analysis included classification of the geothermal resources using various geothermal codes; e.g. Australian Geothermal Energy Group's Geothermal

Lexicon,[1] Canadian Geothermal Code for Public Reporting[2] and the United Nations Economic Commission for Europe (UNECE).[3] The Australian and Canadian geothermal reporting codes build upon the International Reporting Template CRIRSCO (Committee for Mineral Reserves International Reporting Standards).[4] The UNECE has proposed minimum standards on reporting geothermal resources and reserves that build upon the United Nations Framework Classification (UNFC) on fossil energy and mineral reserves and resources. **Figure 2** presents a classification system published by the Leibniz Institute for Applied Geophysics in 2018.[5]

Figure 2: Geothermal Resource and Reserve Classification

Category		Commerciality	Definition	*p*-Value	Required	Units
Reserve	Proved	Commercial production can be expected for the stated lifetime	In operation or new facility prior commissioning	Does not apply	Wellhead and injection temperature ($T_p + T_i$). Installed geothermal capacity with proof of sustainability.	°C MW_{th} MW_e (opt.)
Reserve	Probable	Feasible with existing technology, prevailing market conditions, and available subsidies. Huge chance of economic viability.	Not yet utilized geothermal resource. Estimate based on notional or planned projects. Sufficient seismic and well test data to characterize temperature, transmissivity and reservoir size. Acceptable confidence about fluid chemistry.	P50	Predicted wellhead and injection temperature ($T_p + T_i$). Capacity estimates for new doublets near existing geothermal facilities or existing facilities without proof of sustainability.	°C MW_{th} MW_e (opt.)
Resource	High Confidence	Feasible with current or future technology and prevailing or more favorable market conditions or subsidies	Low estimate. Sufficient data to characterize temperature and reservoir size. Indicators for hydraulic conductivity (e.g., well logs, cuttings, core samples, outcrop analogues etc.) and fluid chemistry.	P90	Predicted reservoir temperatures and utilization scenarios with reasonable injection temperatures. Estimate of geothermal capacity per doublet. Optional: potential capacity per km².	°C MW_{th} MW_e (opt.)
Resource	Moderate Confidence		Best estimate. Sufficient data to characterize temperature and reservoir size. Indicators for hydraulic conductivity (e.g., well logs, cuttings, core samples, outcrop analogues etc.) and fluid chemistry.	P50	Predicted reservoir temperatures and utilization scenarios with reasonable injection temperatures. Best estimate of geothermal capacity per doublet. Optional: potential capacity per km².	°C MW_{th} MW_e (opt.)
Resource	Low Confidence		High estimate. Sufficient data to characterize temperature and reservoir size. Indicators for hydraulic conductivity (e.g., well logs, cuttings, core samples, outcrop analogues etc.) and fluid chemistry.	P10	Predicted reservoir temperatures and utilization scenarios with reasonable injection temperatures. Estimate of geothermal capacity per doublet. Optional: potential capacity per km².	°C MW_{th} MW_e (opt.)

Source: Agemar et al., 2018

[1] "Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves," Australian Institute of Geoscientists: https://www.aig.org.au/about-aig/geoscience-news/geothermal-code/

[2] "The Canadian Geothermal Code for Public Reporting: Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves," Canadian Geothermal Energy Association, (2010): https://www.cangea.ca/uploads/3/0/9/7/30973335/canadiangeothermalcodeforpublicreporting.pdf

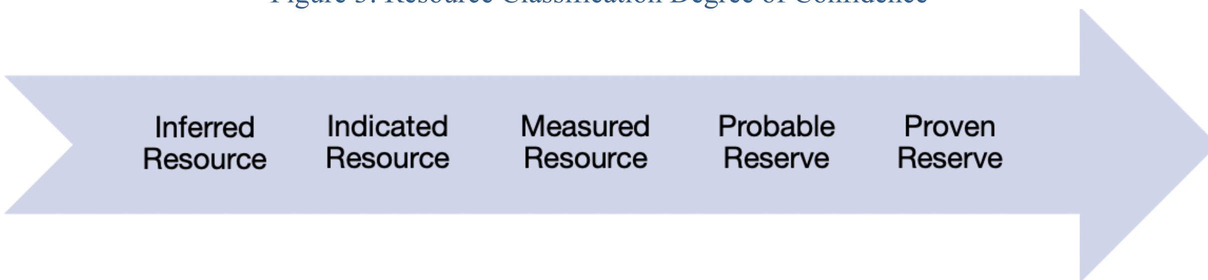
[3] "Specifications for the Application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to Geothermal Energy Resources," United Nations Economic Commission for Europe, (2016): https://www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC2009_publcom.geoth.2016/Geothermal.Specs_for.public.comment.pdf

[4] "Committee for Mineral Reserves International Reporting Standards: CRIRSCO International Reporting Template," International Council on Mining and Metals: http://www.crirsco.com/templates/CRIRSCO_International_Reporting_Template_November_2019.pdf

[5] Agemar, T., Weber, J. and Moeck, I., "Assessment and Public Reporting of Geothermal Resources in Germany: Review and Outlook," Leibniz Institute for Applied Geophysics, (February 2018): https://www.mdpi.com/1996-1073/11/2/332

Using this approach and the Australian Lexicon guidelines, an enhanced classification methodology was adapted for this study and is presented in **Figure 3**.

Figure 3: Resource Classification Degree of Confidence



- Inferred Resource - Low Confidence
- Indicated Resource - Moderate Confidence
- Measured Resource - High Confidence
- Probable Reserve
- Proven Reserve

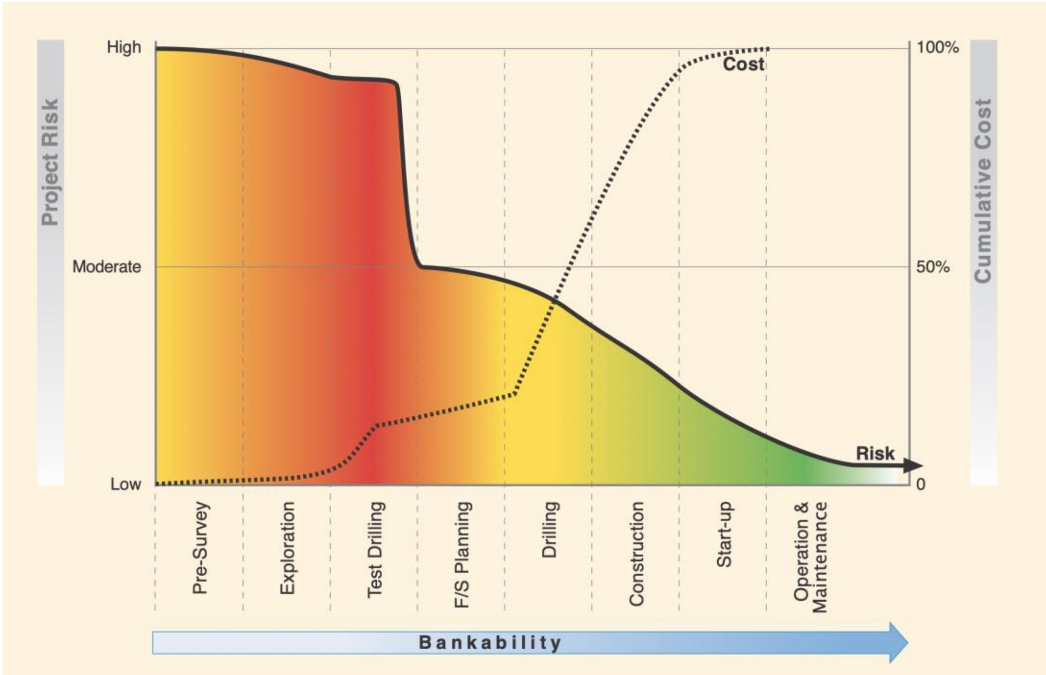
The criteria used to make these classifications included a total of 56 indicators covering various topics, including volume, deliverability, cut-off temperature, base temperature, permeability and pressure, chemistry and recoverability etc. (see the **Appendix** for more details). These indicators were utilized to systemically classify each geothermal resource into the five categories defined above; the availability and quality of data played an important role in this process. For example, for a given resource to be designated as a "Proven Reserve," in addition to meeting all of the necessary indicators, this categorization would also depend on ground-truth data from the site (e.g. well test data with measured and reported temperatures). The availability of data was also assessed as part of the categorization process, with a numerical score of "1" assigned if a given data point existed and a score of "0" assigned if it did not. A total score was then assigned to each identified resource and the top five sites in each country were classified along a spectrum from an "Inferred Resource" (lowest degree of confidence) up to a "Proven Reserve" (highest degree of confidence) as illustrated in **Figure 3**.

The second phase of analysis focused on geothermal project development risks. The World Bank Energy Sector Management Assistance Program (ESMAP) Geothermal Project Risk graphic (**Figure 4**)[6] illustrates the relative magnitude of risks and costs incurred as a geothermal project progresses through its various stages of development. Although cumulative costs increase along each successive stage of development, a greater understanding of field characteristics leads to a reduction in project risk. The breakthrough in risk reduction typically occurs when the resource is confirmed through test drilling, as this significantly mitigates exploration risk and improves the project's overall bankability. More advanced projects typically show more promising geothermal development in the long run.

Using existing/available data in each country, each geothermal resource was assigned a weighted score based on project risk, cost and bankability (**Figure 4**) and then categorized according to its associated status of project development (**Figure 5**). See the **Appendix** for more details, including a full list of the indicators/metrics that were used in the weighted scoring.

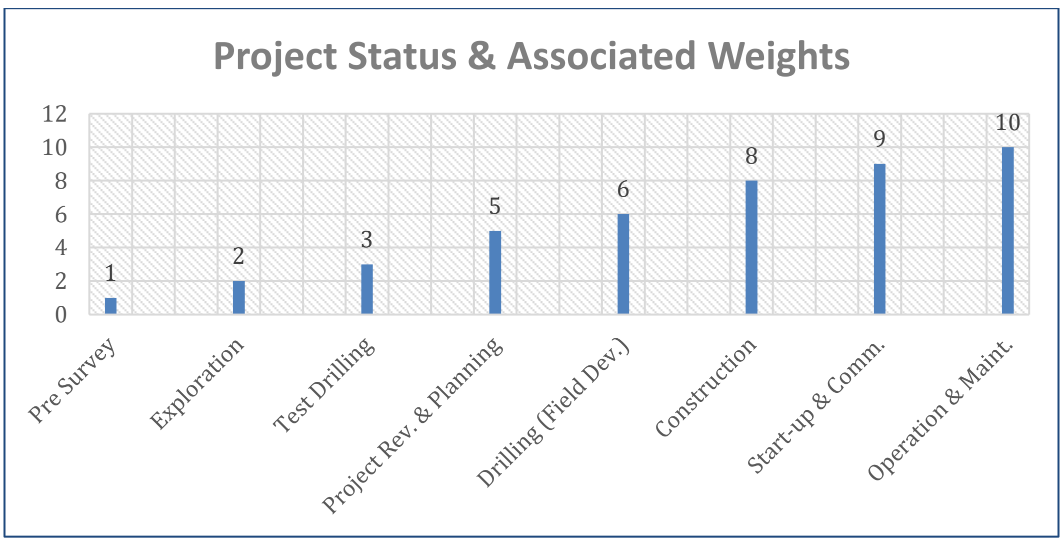
[6] "Geothermal Handbook: Planning and Financing Power Generation, Technical Report," World Bank Energy Sector Management Assistance Program, (2012): https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/FINAL_Geothermal%20Handbook_TR002-12_Reduced.pdf

Figure 4: Geothermal Project Risk and Cumulative Investment Cost



Source: World Bank ESMAP

Figure 5: Geothermal Project Development Status and Associated Weighted Scoring



Source: GreenMax Capital Advisors analysis

- Pre-survey
- Exploration
- Test Drilling
- Project Review and Planning
- Drilling (Field Development)
- Construction
- Start-up and Commissioning
- Operation and Maintenance

In the weighted scoring system presented in **Figure 5**, projects in their initial stages of development were assigned lower values (1-5), whereas projects in more advanced stages of development and moving towards construction and operation were assigned increasingly higher values (5+). Thus, the total weighted score of a given project closely mirrored its level of development. The higher the overall score, the more preferred the geothermal site.

The resource classification and project development status assessment together provided a detailed understanding of the geothermal sites/resources in each country. This two-phased approach and was utilized to analyze and compare sites and ultimately to select the top three sites in each country. The three selected sites generally included a combination of the most advanced/developed project(s) in the country along with additional promising resources, focusing on low to medium temperature resources where applicable and/or projects considered to be technically and financially viable with reduced project development risk.

II. REVIEW AND ANALYSIS OF EXISTING DATA

This section provides an overview of the existing data in each country. The summary includes analysis of existing low-to-medium temperature geothermal resources, as well as gaps in existing data and where additional studies are needed. Based on the data available for each country (reports, feasibility studies, maps etc.) the proposed sites suitable for geothermal direct use applications have been identified and/or validated using the methodology described in **Section I** of this report.

2.1 DJIBOUTI

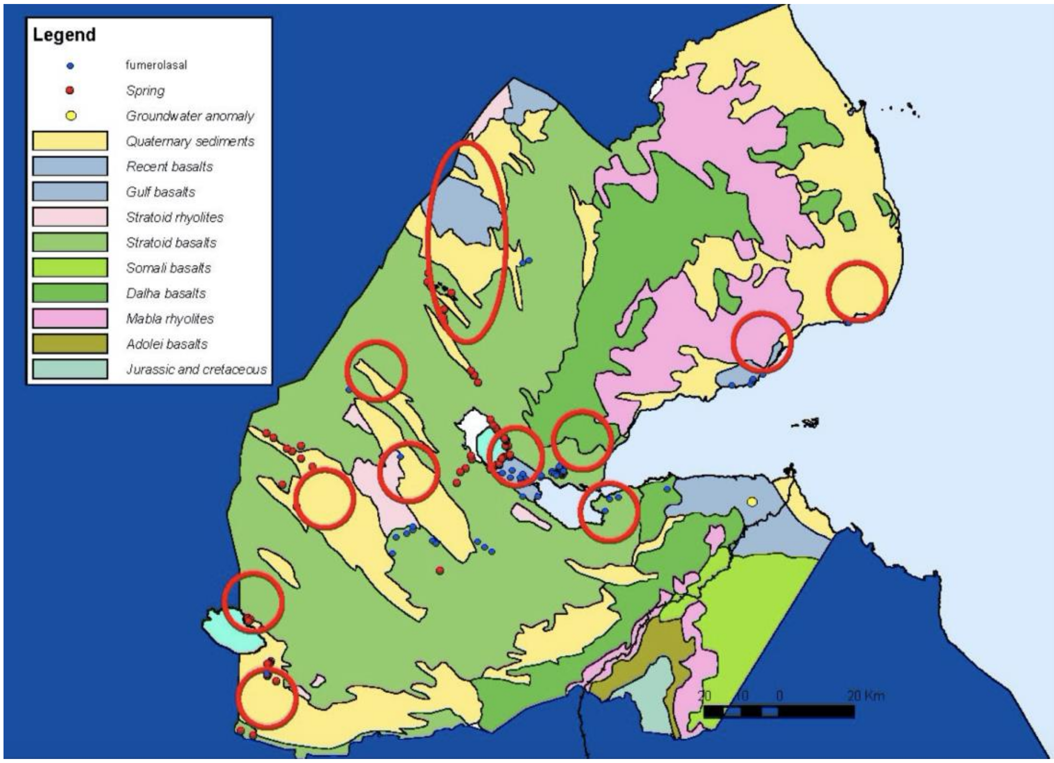
2.1.1 Geothermal Sector Overview

Since 1970, Djibouti has a long history of geothermal resource exploration, as the country is endowed with numerous geological structures. Djibouti’s location at the juncture of three main active geological structures, and the presence of numerous surface geothermal manifestations such as hot springs and fumaroles, gives the country vast geothermal energy potential. Yet, the country still relies heavily on imports from Ethiopia to meet energy demand, as its installed capacity of 120 MW is insufficient for the economy.

In 2014, the government established a specialized agency, Office Djiboutien de Développement de l’Énergie Géothermique (ODDEG), to lead development of the country’s geothermal resources. With support from development partners, ODDEG has commissioned several studies, leading to the discovery of an estimated 1,000 MW of geothermal potential. Initial exploration drilling, however, found that high temperature resources were difficult to identify away from active magmatic heat sources (as shown at Hanlé), and other factors such as salinity limited the exploitation potential of the resource (e.g. in the Asal high temperature geothermal site) at that current state of technology.

Various initiatives have supported geothermal development in the country to date, including the United Nations University Geothermal Training Program among other capacity building and technical assistance programs from bilateral partners (e.g. Iceland, Japan, and German government agencies). Exploratory studies have been completed in the Lake Abhe prospect with technical support from Iceland GeoSurvey; at the Hanle-Garabayiss area with support from the Japan International Cooperation Agency (JICA); and at the Sakalol-Harralol geothermal field carried out by ODDEG with support from Centre d'Etude et de Recherche de Djibouti (CERD). The country also raised USD 30M for exploration drilling in the Asal-Fiale geothermal field from the World Bank, African Development Bank (AfDB), OPEC Fund for International Development (OFID) and Agence Française de Développement (AFD). A feasibility study found between 50-150 MW of geothermal potential at the Asal-Fiale site.

Figure 6: Map of Geothermal Sites in Djibouti[7]



Source: Ministry of Energy and Natural Resources

2.1.2 Summary of Available Data and Gaps in Data

A summary of the data that was available for Djibouti is presented in **Table 1**.

Table 1: Summary of Existing Data Available for Djibouti

Name of Document/Report	Source	Date (publication)	Name of geothermal site(s)
Field Geology of Ambado-PK20	World Geothermal Congress	2020	Ambado-PK20
JICA's Global Geothermal Development Assistance	World Geothermal Congress	2020	N/A
Geophysical study on Lake Abhé Geothermal Prospect, Djibouti	ODDEG	2018	Lake Abhe
Geochemical and Isotopic Interpretation of Boreholes, Waters from Ambado-PK 20 area, Djibouti	ODDEG	2018	Ambado-PK20
Geological Survey of Ambado-pk20, Djibouti	ODDEG	2018	Ambado-PK20
MT and gravity surveys in Ambado-PK20 geothermal prospect, Djibouti	ODDEG	2018	Ambado-PK20

[7] Moussa, O. and Souleiman, H., "Country Report, Geothermal Development in Djibouti Republic," Ministry of Energy and Natural Resources, (World Geothermal Congress, 2015): http://agid.theargeo.org/reports/Djibouti/Country%20Report-%20Geothermal%20Development%20in%20Djibouti.pdf

Name of Document/Report	Source	Date (publication)	Name of geothermal site(s)
Geothermal Development in the Republic of Djibouti: A Country Update Report	ODDEG	2016	Country-wide
Asal-Fiale Geothermal Project Planning, Drilling and Testing	Geologica	2015	Asal-Fiale
Country Report, Geothermal Development in Djibouti Republic	Ministry of Energy and Natural Resources, Djibouti	2015	Country-wide
Geothermal Well Design for the Future 4 Wells in the Lava Lake Area in Caldera Fiale in Djibouti	Ministry of Energy and Natural Resources, Djibouti	2015	Lava Lake Area, Caldera Fiale
How to Generate Electricity in the Republic of Djibouti?	Sui Shao-qiang, for the WGC	2015	Asal 1-6
Prefeasibility Design of Single Flash in Asal Geothermal Power Plant 2x25 MW, Djibouti	Ministry of Energy and Natural Resources, Djibouti	2015	Asal
Problems Encountered While Drilling and Completion Stages in Asal Rift Wells, Djibouti	Djiboutian Development Office of Geothermal Energy	2015	Asal
The Obock and Rouéli Geothermal Sites, Djibouti Republic	Ministry of Energy, Water and Natural Resources, Djibouti	2015	Obock and Roueli Sites
Asal-Fialé geothermal field (Djibouti republic): A new interpretation for a geothermal reservoir in an actively spreading rift segment	Geo2D	2014	Asal-Fiale
Data Collection Survey on geothermal development in Djibouti	JICA	2014	N/A
North-Ghoubhet Geothermal Site	Ministry of Energy, Djibouti	2014	North-Bhoubhet
Djibouti Project Appraisal Report	ADBG	2013	Lake Assal Region
The Asal Geothermal Site, Djibouti Republic	Ministry of Energy, Water and Natural Resources, Djibouti	2012	Asal
A Revised Approach to the Hanlé - Gaggadé (Djibouti Republic): The Garabbayis Geothermal Site	Ministry of Energy, Water and Natural Resources, Djibouti Republic	2012	Hanlé – Gaggadé
Geothermal Development in Djibouti Republic: A Country	Ministry of Energy, Water and Natural Resources, Djibouti Republic	2012	Country-wide
The Obock and Rouéli Geothermal Sites, Djibouti Republic	Ministry of Energy, Water and Natural Resources, Djibouti Republic	2012	Obock and Rouéli
Proposal for New Geothermal Models and Sites Hierarchy in Djibouti Republic	Ministry of Energy, Water and Natural Resources, Djibouti Republic	2012	Country-wide
Djibouti Potential Status and Prospects in Geothermal Resources Development	Farah Ali Ainan, for the WGC	2010	Country-wide

Name of Document/Report	Source	Date (publication)	Name of geothermal site(s)
Geothermal Resource Assessment of Asal Field, Republic of Djibouti	Daher Elmi Houssein, for the WGC	2010	Asal Field
Project Completion Report, Djibouti	World Bank	1993	Hanle 1 & 2
JICA's Cooperation in Geothermal Development at Great Rift Valley in Africa	JICA	No date	N/A
Geothermal Development in East Africa, Republic of Djibouti	Ministry of Energy and Natural Resources, Djibouti	No date	Country-wide

From the studies and reports provided in **Table 1**, 10 geothermal sites were identified as promising for geothermal power generation and/or direct use purposes. Three sites were short-listed using the methodology described in **Section I** of this report. As is described below, advanced technical data (e.g. test drilling, short-term well testing, pre-feasibility and feasibility studies) was largely not available for the three short-listed sites. In some cases, studies of surface manifestations, hot springs and fumaroles were conducted; however, it is recommended that further analysis be undertaken (e.g. to assess geochemical results for brine and gas), as there are inconsistencies in some of the data/results.

2.1.3 Summary of Findings and Geothermal Site Selection

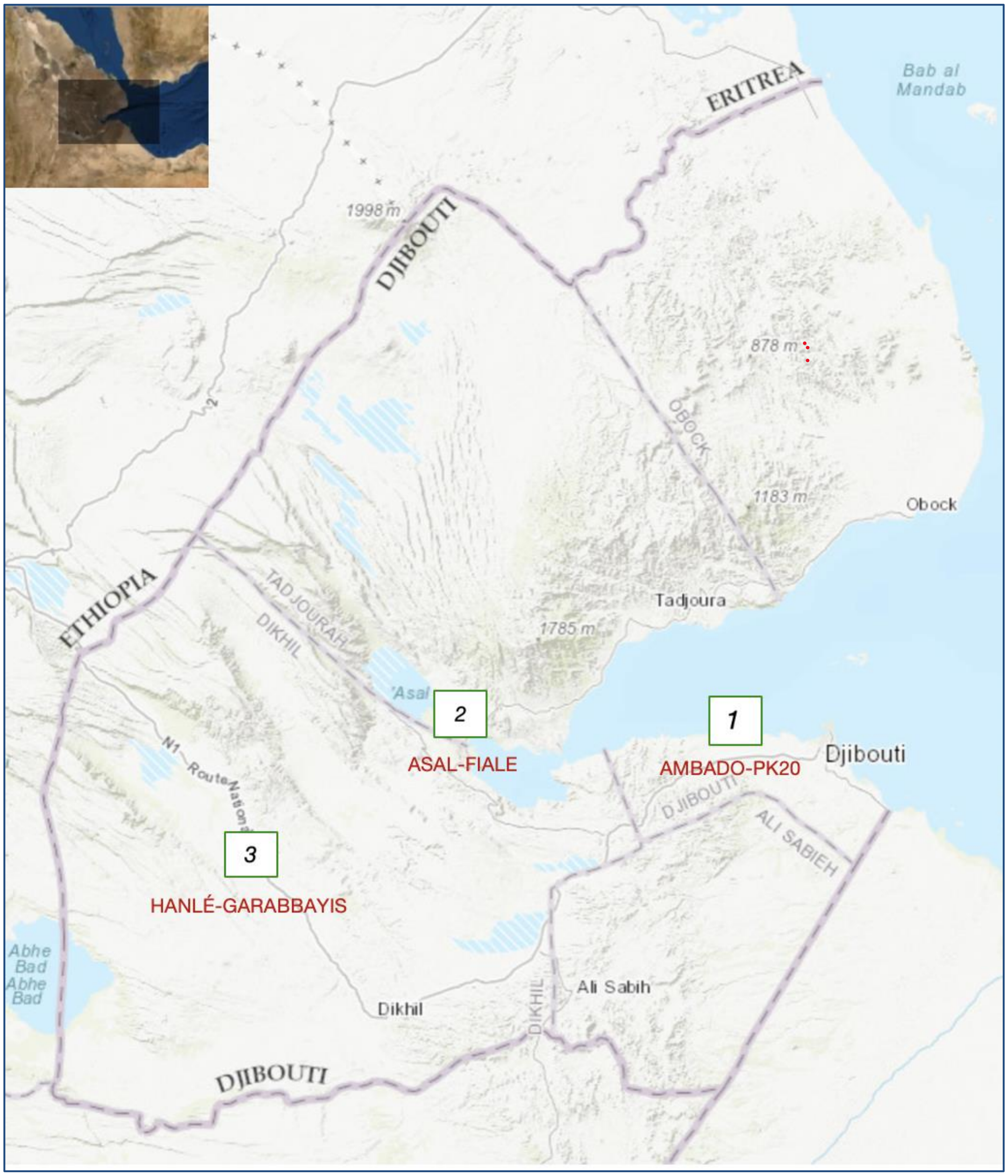
Available data identified 10 sites in Djibouti, including: Ambado PK20, Asal Fiale, Hanle, Lake Abhe, Obock, Manda Inakir, Roueli, North Ghoubhet, Lava Lake in Caldera Fiale and Sakaol. From this list, the top three sites identified for Djibouti are shown in **Table 2** and **Figure 7**.

Table 2: Geothermal Site Selection and Weighted Scoring for Djibouti

No.	Geothermal Resource	Classification	Classification Score	Project Weighted Score
1	Ambado PK20	Probable Reserve	41	18
2	Asal Fiale	Probable Reserve	38	55
3	Hanle Garabbayis	Indicated Resource	28	25

Source: GreenMax Capital Advisors analysis

Figure 7: Map of Selected Geothermal Sites in Djibouti



No.	Geothermal Site
1	Ambado-PK20
2	Asal-Fiale
3	Hanle-Garabbayis

Source: ARGeo Africa Geothermal Inventory Database; GreenMax Capital Advisors analysis

(1) AMBADO-PK20

Geology

The Ambado-PK20 geothermal prospect is located under a monitoring well, which supplies water to the city of Djibouti, adjacent to Gulf of Tadjourah. The geology of the country is marked by the triple joint convergence between three plates that created the Afar depression; the Red Sea, the Gulf of Aden and the East African rift. The Ambado-PK20 study area presents several types of volcanic formations; the Gulf basalt linked with the Tadjourah opening, the Dalha basalt to the south in the "Bour Ougoul" massif and the Somali basalt to the south-east and the Mabla rhyolite. The sedimentary wadis seen in the Ambado sector drain into the basalt formations in the Gulf. The tectonic structure is expressed by three families of faults which are the N80° faults at 120° almost E-W, the N10° almost N-S faults and the N60° and N150° faults. The contact between these geological formations and tectonic fabrics is related to the opening of the Gulf of Tadjourah. There is an NW-SE fault network that is responsible for the formation of the Ambado graben in the direction of the Tadjourah rift and an E-W fault parallel to it. The blocks remain fractured and permeable. The intersection of the major N-S and E-W trending faults suggest geothermal geology analogy within the prospect and thus seen in the geothermal gradient in the three monitoring wells.[8]

Geothermal Manifestations

Many fumaroles and hot springs can be found throughout the country. In the Ambado-PK20 prospect only surface thermal manifestations can be seen and are mainly concentrated on the ridge of the Hayabley volcano. Mofette-like emanations (fumaroles with a temperature close to ambient temperature) have also been observed.[9]

Geochemistry

Fluid chemistry data shows that the fluid composition meteoric and mostly dominated by NaCl. Similar isotope ratios to groundwater in Djibouti city have been measured in Awroful wells. The hot water from the Awrofoul No.2 well showed 73.6 °C, and alkaline geochemical thermometer indicated (Na- K) 191 °C. The electric conductivity is as low as 1,400～1,080 μS/cm. Given the slow reaction rate of Na-K, it can be expected that Na-K temperature correctly reflected the temperature information in deep depth. If this assumption is accurate, it is highly possible that areas of high temperature (about 200 °C) exist underground in these locations. Recharge water might be regional precipitation and locally mixed with seawater.[10]

Geophysics

Magnetotelluric (MT), transient electromagnetics (TEM) and gravity surveys were carried out in Awroful to delineate the boundaries of the geothermal system. A total of 34 MT/TEM soundings were acquired using metronix equipment with a periods range between 0.001s and 800s. 66 Gravity measurements were collected with a Scintrex CG5 gravimeter. A geoelectric structure model obtained by the 1-D inversion shows a resistive layer at the surface overlaying a conductive layer and a deep resistive layer. Residual anomaly shows a central low gravity extended towards the south and delineated by a heavy body in the northern part of system. Based on interpretation of results from both 1-D inversion of MT data and Bouguer anomaly, the conductive layer is found in the area defined by a low gravity value. This correlation can be

[8] Hassan M., Suge, A., Idriss, A., "Field Geology of Ambado-PK-20 (Djibouti)," World Geothermal Congress 2020: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/12006.pdf
[9] Ibid.
[10] "Data Collection Survey on Geothermal Development in Djibouti: Draft Final Report," Japan International Cooperation Agency (JICA), 2014.

associated with the cap rock of the system, which is an impermeable layer affected by hydrothermal alteration, and is responsible for reducing the resistivity and the mass of the rock. The results show strong correlation with thermal anomalies found in the area.[11]

- **Monitoring Wells**

The water reservoir for wells of Awroful 2, 5 and 6 are within the basalt of the Gulf. The respective altitude is 118 m, 85 m and 135 m above sea level. The static water level of Awrofoul 2 is about 100m. Drill cuttings from the boreholes were analyzed for geothermal signature. Faults that pass near the boreholes tend to join the initial direction of the Tadjourah rift (E-W). Similarly, the water level drops from 72m depth in Awrofoul 5 to 118 m in Awrofoul 6, which suggests that the well crossed a fault.[12] Additionally, 26 boreholes' samples from the Ambado-PK20 site were taken in-situ temperature, pH, conductivity and verification or updating coordinates of the borehole's waters. The results of the analysis showed that PK-12 Dorale water is slightly mineralized with conductivity between 1236 and 2482 µS / cm. In Nagad, Douda and Damerjog zones, the samples are strongly mineralized, with conductivities between 4300 and 13900 µS / cm. The pH values of these samples are between 7 and 7.9, which show that they are neither basic nor acidic. The temperature of samples varies between 37.3-61.4 ° C. For the PK20-9 borehole, the thermal profile shows a temperature increase of approximately 12°C over 100m.

- **Conceptual Model**

The intersection of the major N-S and E-W trending faults and the location of the monitoring wells shows that the reservoir is fault controlled. The aquifer is hosted within the basaltic unit – this is the mixture of scoriaceous basalt and fractured basalt that serves as a reservoir of water in the region. From the MT and gravity studies, and the correlation with the wells, the basement, reservoir rock and the cap rock were identified.[13] The hot water from well Awrofoul No.2 showed 73.6°C, and alkaline geochemical thermometer indicated (Na- K) 191 °C (of which is extrapolated as 200°C in the deeper zones by JICA experts). Also, the electric conductivity is as low as 1,400～1,080 µS/cm. The geothermal gradient from PK20-9 is 12 °C over 100m.

- **Preliminary Assessment**

The Ambado-PK20 prospect has been classified as a "Probable Reserve" and has a relatively low weighted score in the analysis.

Contrary to generally high saline geothermal resources in Djibouti, the Ambado-PK20 geothermal prospect has low salinity, indicating relatively low geochemistry risk. This is especially important for low- moderate geothermal enthalpy resources and for their utilization, as the lower the geochemistry risk, the more favorable the technology and economics for the project. The water wells are used as drinking water supply for the city, therefore wells already exist and are operating, which will expedite the launch of any direct use applications. Measured well temperatures range from 37-73°C while the geothermometers give a high temperature of 200°C in the deeper zones. The geothermal system is defined as a fault/ fracture controlled hydrothermal resource. Further studies are required to evaluate the interaction between the immature waters and deep saline water mixing trends to assist in reservoir characterization.

[11] Ibrahim N., Bileh M., Mohamed H., "MT and gravity surveys in Ambado-PK20 geothermal prospect," 7th African Rift Geothermal Conference, (31 October – 2 November 2018).
[12] Hassan et al., 2020.
[13] Ibrahim et al., 2018.

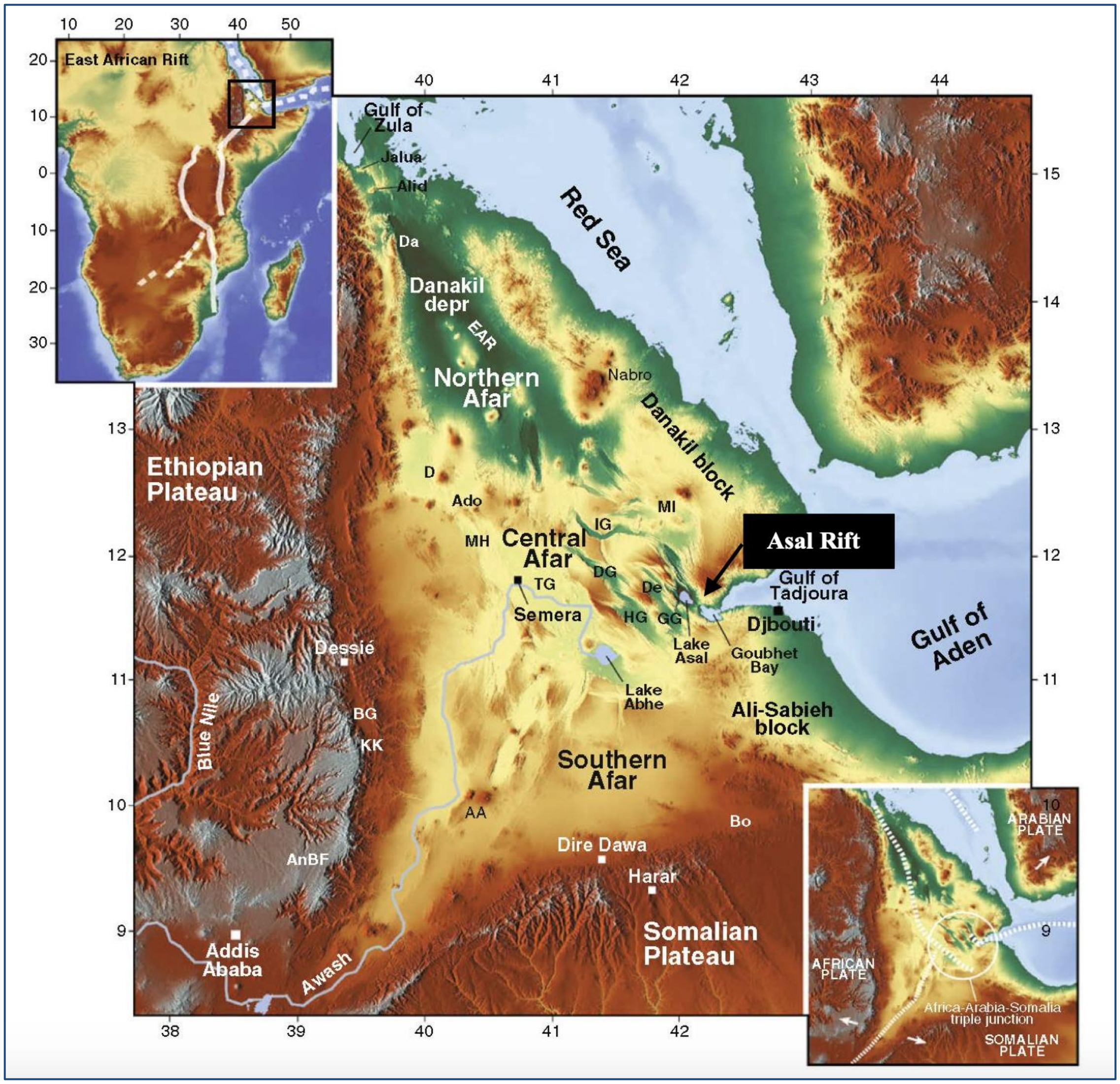
These studies should include:

- Temperature and pressure (PT/ PTS) logs from the wells
- Additional targeted test drilling
- Permeability and porosity identification from litho-stratigraphic information
- Updated conceptual hydrogeological model

Compiling all of this into a prefeasibility study would be beneficial, as the geothermal prospect is worthy of further investigation for the possibility of geothermal direct use applications.

(2) ASAL FIALE

Figure 8: Map of Asal Fiale Geothermal Prospect



Source: Geologica Geothermal Group

- **Geology**

The Asal range runs from Goubet Lake into Ethiopian territory. The Asal active volcanic and tectonic range displays a continuous basaltic movement in the recent Quaternary Period, with a magmatic heat source at shallow depth. Asal shield volcano was formed in the last 300.000 years and was subject to successive rifting episodes with an equilibrium established between extension – of 17 to 29 mm / year along a 40° North direction – and magma injection.[14]

Deposition in the region constitutes three main rock series,[15] the oldest of which is the Dalha Basalt Series. It is a sequence of lava flows intercalated with rhyolites, trachytes and detritic deposits. The Afar Stratoid Series overlies the Dalha Basalt Series in the Asal Rift. It is comprised mainly of basalt, with intercalated intermediate products, including trachytes and rhyolites. The youngest rock series in the region is the Asal Series, containing the recent basalt lava flows as well as hyaloclastites generated at the onset of the volcanism of the Asal Rift.[16]

The Fiale caldera is situated in the Asal Rift axial graben between two boundary rift faults trending WNW. It is traversed by multiple intersecting N, E, ENE-trending faults and fractures as well as NW-trending fractures having both extensional and shear components.[17] Echelon patterned fractures can also be seen oriented NNW-SSE in rift zone.

- **Geothermal Manifestations**

Two types of surface manifestations in the Asal rift area are related to the Fiale Caldera geothermal system. These include warm and hot springs at the north end of the rift, fumaroles and hydrothermal alteration within the rift and fumaroles within the Fiale Caldera. These occur along NW, ENE, and WNW-trending faults on the northeast and southwest quadrants of the caldera. Thermal springs around Lake Asal (30°C to >80°C) appear to be seawater sourced, which is heated and slightly altered by interaction with basalt.[18]

- **Geochemistry**

Hydrogeological studies of the region show a general groundwater flow toward Lake Asal, which is the lowest point of the area and is occupied by a salt lake saturated mainly in NaCl and $CaSO_4$.[19] To the southwest (wells A-1, A-2, A-3, A-6), sea water has interacted with rocks at depth to generate hypersaline brine; a shallow 100-130°C hot zone in scoriaceous basalt and deep 260°C zone of fractured Dahlia basalt underlying clay layers. No shallow cold seawater is reported. Sea water flows through major NW trending rift faults to discharge as warm/hot springs along Lake Asal. The geothermal well water has high portion of seawater that has been heated through interaction with rock at high temperatures. This process resulted in the depletion of magnesium while enriching the fluid in potassium, sodium, and chloride contents.[20]

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[14] De Chabalier, J.-B., and Avouac., J.P., "Kinematics of the Asal Rift (Djibouti) Determined from the Deformation of Fieale Volcano," Science, 265, no. 5179 (September 16, 1994): 1677–81. https://doi.org/10.1126/science.265.5179.1677.

[15] "Geothermal Exploration Project: Republic of Djibouti, Final Report," AQUATER and Government of Djibouti, ISERST, 1989.

[16] "Asal-Fiale Geothermal Project Planning, Drilling and Testing - Conceptual Model of the Geothermal System for Well Targeting," Geologica Geothermal Group, 2015.

[17] Ibid.

[18] Sanjuan, B., Michard, G. and Michard, A., "Origine des substances dissoutes dans les eaux des sources thermales et des forages de la région Asal-Ghoubbet (République de Djibouti)," Journal of Volcanology and Geothermal Research, 43, no.1 (October 1, 1990): 333–52.

[19] Houssein, D., "Geothermal Resource Assessment of Asal Field, Republic of Djibouti," Proceedings World Geothermal Congress, 2010.

[20] Geologica, 2015.

- **Geophysics**

The Bureau de Recherches Géologiques et Minières (BRGM) conducted a gravity survey in the Asal Region in 2008, which found high gravity in the older rocks outside of the rift and in North Ghoubbet Bay as well as through the Fiale Caldera and to its immediate south. Gravity is relatively lower in the southwest part of the rift, interpreted as being due to lower density hyaloclastite deposited underwater, as shown in the shallower sections of wells A-3, A-4, and A-6.

A 106 station MT survey was conducted to supplement the TEM survey. Though this study provided some results, it had limitations, especially in the 3D deep imaging.[21] The MT survey shows that the Asal Rift has an extensive clay cap that varies rapidly in character across strike and is more consistent along strike. It is truncated at the edges of the rift and is thinner and less conductive in the recent lavas that cap the Fiale Caldera. The dip in the base of the clay cap on the northwestern margin of the Fiale Caldera is consistent with an up-flow in the Fiale Caldera, boiling and then outflowing beneath the clay cap up dip past the 70ºC zone found at 500 m depth in well A-5.

CERD monitors the micro-seismic activities of Asal-Fiale area at the monitoring station in Arta Town, enabling further detailed interpretations of the region. The micro seismic data indicates that the spreading axis has most recently been active through the Fiale Caldera. Brittle rock exists between 1500 m and 3500 m, where most of the seismicity has occurred. Below 3,500 m, the rocks become increasingly ductile with the increase in temperature with depth, explaining the lack of deep seismicity.

- **Asal Wells**

A total six wells were drilled in this area from 1975 to 1988, namely A1-6. Wells A-1, A-3, and A-6 were drilled within 250 m of each other and had similar productive zones near 240 m depth, from 400 to 550 m depth, and from 1050 to 1316 m depth. Well A-6 appeared to reach a >260°C near-isothermal reservoir. Wells A-2, A-4, and A-5 were unproductive, lacking sufficient permeability in the uncased part of the borehole to flow. However, all wells exceeded 240°C at shallower than 1,750 m depth. Wells A-5 and A-6 showed profound temperature reversals from roughly (-500 m) to (-1300 m) elevation, consistent with the regional northwesterly flow of cool ocean water that is warmed on its way to Lake Asal.

Three wells have been discharge tested A-1, A-3 and A-6[22] and measurements have shown total well flow in the range 20-60 kg/s. The best producer is A-3, which under stabilized conditions has produced about 40 kg/s of fluid, 4-5 kg/s of which is steam. A three month test of the well showed a significant decline in production that was interpreted due to formation of deposits in the pipelines hampering the flow. The enthalpy of the fluid was in the range 1069 – 1090 kJ/kg. A pressure connection has been found between well A-3 and A-2 and A-6, but wells A-4 and A-5 did not respond to flow testing of A-3. The reservoir's permeability was found to have an average porosity of 5% or less. The size of the drainage area for well A-3 was observed to be in the range 7-9 km^2.[23]

- **Conceptual Model**

The conceptual model for the Fiale Caldera is supported by the geoscientific evidence and incorporates four elements: 1) heat source, as evidenced by the aseismic zone comprising hot ductile rocks at depths greater than 3.5 km; 2) water recharge, shown by both near-surface and deep seawater cross flows; 3) permeability,

[21] Geologica Geothermal Group, 2015.
[22] Virkir-Orkint. "Djibouti. Geothermal scaling and corrosion study. Final report." Electricité de Djibouti, (1990).
[23] Ibid.

demonstrated by the faults, fractures, and micro seismic zones displaying brittle fracturing; and 4) a clay cap, evidenced by the electrical conductor imaged with MT and TEM.[24]

- **Preliminary Assessment**

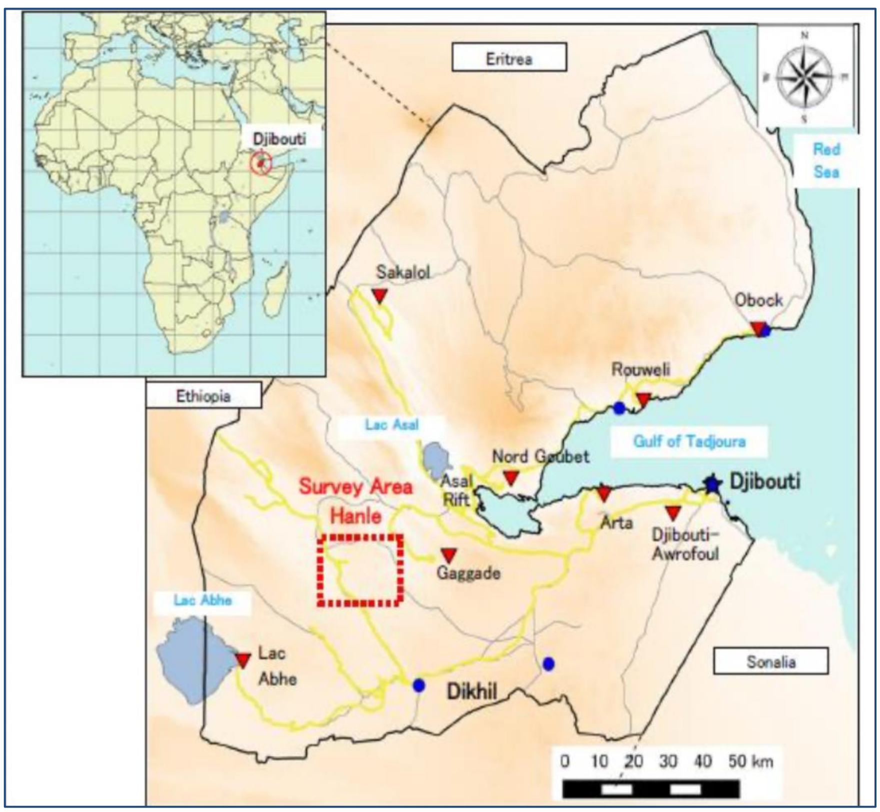
The Asal Fiale prospect has been classified as a "Probable Reserve" and has a high project weighted score in the analysis.

The Asal Fiale reservoir is mainly vapor dominated and reaches very high temperatures such as 360°C at around 2100 m depth. It has a high salinity ratio in the geochemistry which poses high risks to the applications, but there are preventive measures that can be implemented for issues like scaling and corrosion sourced from this high salinity.

This is the most advanced project in the country and has funding and projects secured (USD 30M from the World Bank AfDB, OFID and AFD) for the next phases of project development. As the most technically advanced prospect, with defined conceptual model and drilled wells, this site is proposed to be one of the projects that can be utilized for cascading geothermal technologies, where output from the power plant can be applied to several different direct uses.

(3) HANLE GARABBAYIS

Figure 9: Map of Hanle-Garabbayis Geothermal Prospect



Source: ODDEG

[24] Geologica Geothermal Group, 2015.

- **Geology**

The Hanle-Garabbayis site is located west of the city of Djibouti, about 110 km from the urban area in the Afar Stratoide series distribution zone, which is mainly composed of Quaternary Pliocene basaltic rocks. The alluvial and marine lake deposits covering the Hanle Plain and the Afar stratoid series are distributed underground. This Quaternary tectonic structure is bounded by faults trending in the NE-SW direction, which corresponds to the spreading of the Red Sea – Gulf of Aden plate boundary between Africa and Arabia. Among the volcanic rocks in the survey area, altered minerals of zeolite, calcite and quartz were identified through XRD analysis. Additionally, the presence of widespread calcite hydrothermal dike and accompanying altered minerals were confirmed.[25]

Tectonically, the region of the Hanle represents a graben delimited by two horsts. This graben is about 50 km long and 20 km wide in NE direction in the center and shrinks progressively to the point of losing its characteristic to the SE. It is filled with alluvium and lacustrine deposits which do not have a very large thickness. The NW-SE tectonic system is connected to the Dimbir transverse system with transforming features, whose present activity is demonstrated by the alignment of groups of microseisms and fumaroles.

- **Geothermal Manifestations**

Several thermal manifestations (fumaroles, hydrothermal alterations, hot soils, etc.) were observed along the NW-SE faults limiting the Baba Alou horst and the Hanle and Gaggade graben, extending in a transverse direction (NNE-SSW). These are defined as convective hydrothermal features along faults in the absence of a magmatic heat source (age of the most recent volcanic formations: 1Ma).[26] Geothermal alteration studies showed that Smectite-Chlorite were identified, which suggests a temperature of formation 150-200°C from JICA's 2015 study.

- **Geochemistry**

All of the boreholes (three gradient, two deep wells) in the regional volcanic aquifer show chlorinated-alkaline waters, the same as the springs located in Hanle plain fault along the fault scarps at the contact of basalts with the sediments. In the sedimentary aquifers of the Hanle Plain, water is the chlorinated-bicarbonate-sulfated-alkaline type. Geochemical anomalies in CO2, NH3 and H3BO3 identified deep ascending fluids.

Differing from Asal geothermal field super saline fluid characteristics, the Hanle area contains hot springs with "standard" salinity which is desired as high priority of geothermal development within the region. Fumarolic gas volume suggests gas mixed with mantle origin and reservoir temperature may range from 180°C to 260ºC.[27] The composition of gases indicates leakages from a steam reservoir (with the presence of B and H2). Hydrothermal deposits found in Hanle Area are carbonaceous travertine in the Hanlé graben, silica rich in the Baba'Alou Horst and along the southern fault.

- **Geophysics**

Through geoelectrical prospection (MT/TEM study conducted by JICA in 2015)[28] the thickness of the sedimentary filling was assessed – with low electrical resistivity due to clays – and the surface of the stratoid series was mapped. Aeromagnetic data and a seismic activity were also used in the interpretative model.

[25] JICA, 2014.
[26] Youssouf S. and Hosoda T., "Geological Study of Hanle Geothermal Prospect, Djibouti."
[27] Daher, A. and Fukuda, D., "Geochemical Study of Hanle Geothermal Field, Djibouti," World Geothermal Congress, 2020.
[28] JICA, 2014.

Below the sediments, an upper resistant layer and a lower conductor was identified, with a thickness exceeding 200 m, interpreted as signs of hydrothermal alteration or intercalated layers of fluviatile sediments with paleosoils in the upper part of the stratoid series. According to the geophysical analysis, the permeable reservoir could be along NW-SE fault/fracture system that is located around the fumaroles.

- **Wells**

In the early 1980s, three gradient wells at an average of 450 m depth (Teweo-1, Garabayyis-1 and Garabayyis-2) were drilled in Hanlé prospect to confirm the geothermal model and the precise temperature at depth before undertaking deep drillings. Measurements indicated temperatures of up to 121,7°C at Garabbayis-1 at 445 m and a maximum temperature of 87°C on Garabbayis-2 at 75 m. In late 1980s', two deep wells were drilled, named Hanlé-1 (1623m) and Hanlé-2 (2038m) respectively. Hanle-1 recorded a maximum of 72°C at 1420 m while only 124°C at 2020 m in Hanle-2. Highly permeable levels were observed down to 450 m (with fluid TDS 2 g/l) and the rest of the well remains impervious with a dominantly basaltic lithological sequence from the stratoid series.[29]

The permeable intervals encountered in the upper part of the well, at 140-160 m at 250-270 m and around 400 m emplaced in interflow levels or in alluvial beds. The hot aquifer (87°C) at 140-160 m can be correlated with the aquifer encountered at 140-160 m in Garabbayis 2 and at 85 m in Garabbayis 1. Other indices of permeability or water circulation in the formation exist down to about 1,000 m. The formation is nearly impervious below 1,000 m apart from a possible minor water entry at around 1,590 m. The water level in the well was quite constant, around 75-76 m while drilling in the upper aquifers.

- **Conceptual Model**

In JICA's most recent well targeting study conducted in 2014,[30] the Hanle Garabbayis reservoir was studied in detail, with three different conceptual model scenarios prepared along with seven well targeting areas.[31] The authors define the reservoir structure as having fumaroles distributed along the surface boundary between the middle basalt layer and lower basalt layer; the middle basalt layer may play a role in cutting off the pathway of rising fumarolic gas like a cap rock. The Hanle-Garabbayis geothermal field is dominated by faults in the NW-SE direction. Since fumaroles are located on the extension line of the fault, these faults are thought to be the pathway of geothermal fluid. The reservoir should be fractured faults themselves or together with permeable layers in the lower basalt, with capping structure made up of upper basalt. The reservoir could be 260°C according to the geochemical survey. According to the study, the heat source could be a body that shows high resistivity and is considered to be an intrusion body.[32]

The heat source and geothermal reservoir exist underneath the northwest plateau. Additionally, geothermal fluid should be recharged from the Hanle Plain where groundwater levels are higher than in the plateau. The source of fluid could be derived from Ethiopian side (mountain side). The seven well target areas have measured fumarolic gas volumes changing from 98 to 113°C, and one hot spring with 48 °C and one area with no surface manifestation.

- **Preliminary Assessment**

The Hanle Garabbayis prospect has been classified as an "Indicated Resource" and has a relatively low project weighted score in the analysis.

[29] Jalludin, M., "An overview of the geothermal prospections in the Republic of Djibouti. Results and perspectives," KenGen Geothermal Conference, 2003.
[30] JICA, 2014.
[31] Samod and Hosoda, 2020.
[32] JICA, 2014.

The results of the JICA study suggest that Hanle-Garabbayis should be a top priority for development. The JICA team expects the wells to have a productive zone between of 500-1000 m, with production at medium temperature (130°C -170°C). These wells will be drilled with a diameter (at least nine inches for the final production casing) sufficient for a significant flow rate (of about 30 - 100t/h).

As one of the most technically advanced prospects in the country, with a defined conceptual model and drilled wells, this site shows significant promise for direct use applications and/or cascading geothermal technologies.

2.2 ETHIOPIA

2.2.1 Geothermal Sector Overview

Geothermal exploration in Ethiopia, which began in 1969, has revealed the existence of both low- and high enthalpy geothermal resources in the Ethiopian Rift valley and the Afar depression, both of which are part of the East African Rift System.[33] To date, geothermal exploration has identified over 22 geothermal prospects as suitable for electricity generation.[34] Ethiopia's geothermal resource potential is estimated to be about 5,000 MW, with some estimates double this figure. The country is widely considered to have the second greatest geothermal resource endowment among all African countries with only Kenya possibly having a larger potential. As part of its energy sector expansion strategy, the government has announced plans to develop 675 MW of geothermal power in the medium term and 5,000 MW by 2037.

Despite the country's vast potential, development of geothermal resources has progressed slowly. The government has focused in developing two prospects thus far – the Aluto Langano and Tendaho geothermal fields, with only a 7.2 MW plant in operation at Aluto-Langano. In these prospects, detailed surface exploration, test well drillings and feasibility studies have been conducted.[35]

In 2013, the government introduced the first independent power project in its history, agreeing to terms with U.S.-Icelandic private developer Reykjavik Geothermal on the development of the USD 4 billion 1,000 MW Corbetti Caldera geothermal project located in the Ethiopian Rift. The planned project will utilize geothermal energy from three different resources at Corbetti, Tulu Moyer and Abaya and will sell power to the state owned energy company, Ethiopia Electric Power Company (EEP). The plant will be built in two stages, with the plant expected to be fully on-line by 2023. The Power Purchase Agreement (PPA) was signed in 2017,[36] and exploration drilling began in 2019.[37]

2.2.2 Summary of Available Data and Gaps in Data

A summary of the data that was available for Ethiopia is presented in **Table 3**.

[33] Teklemariam, M., Beyene, K., Amdeberhan, Y., and Gebregziabher, Z., "Geothermal Development in Ethiopia," Proceedings World Geothermal Congress, 2000.
[34] "Aluto Langano Geothermal Field – Appraisal Project in the Federal Democratic Republic of Ethiopia: Resource Assessment Report," Japan International Cooperation System (JICS), 2016.
[35] Kebede, S., "Country Update on Geothermal Exploration and Development in Ethiopia. Proceedings, 6th African Rift Geothermal Conference," Addis Ababa, Ethiopia, (2 – 4 November 2016).
[36] Richter, A., "Agreements signed for 500 MW Corbetti Geothermal Project, Ethiopia," Think Geoenergy, (19 December 2017): https://www.thinkgeoenergy.com/breaking-news-agreements-signed-for-500-mw-corbetti-geothermal-project-ethiopia/
[37] Richter, A., "Drilling for Corbetti and Tulu Moye to Start September 2019," Think Geoenergy, (2 June 2019): https://www.thinkgeoenergy.com/drilling-for-corbetti-and-tulu-moye-to-start-september-2019/

Table 3: Summary of Existing Data Available for Ethiopia

Name of Document/Report	Source	Date (publication)	Name of geothermal site(s)
Geological Survey of Ethiopia	Solomon Kebede	2019	Country-wide
Geochemical exploration at Butajira Geothermal prospect area, Central Main Ethiopian Rift, Ethiopia	Geological Survey of Ethiopia	2017	Butajira geothermal
Geothermal Resources Development Proclamation No.981/2016	Democratic Republic of Ethiopia	2016	Country-wide
Country Update on Geothermal Exploration and Development in Ethiopia	Geological Survey of Ethiopia	2016	Country-wide
Aluto Langano Geothermal Field Appraisal Project in the Federal Democratic Republic of Ethiopia - Resource Assessment Report	West Japan Engineering Consultants	2016	Aluto Langano
Country Update on Geothermal Exploration and Development in Ethiopia	Solomon Kebede, Geological Survey of Ethiopia	2016	Country-wide
The Project for Formulating a Master plan on Development of Geothermal Energy in Ethiopia	Nippon Koei Co., Ltd.; JMC Geothermal Engineering Co., Ltd.; Sumiko Resources Exploration & Development Co., Ltd.	2015	N/A
Geothermal Resource Assessment of the Tendaho Area	United Nations Environment Programme	2014	Tendaho
Aluto Langano Geothermal Power Expansion Phase ii Project (Appendices 1-8)	West Japan Engineering Consultants	2014	Aluto Langano
Geothermal Resource Exploration and Assessment Core Process	Ministry of Mines, Ethiopia	2011	Aluto-Langano
Geothermal Resource Exploration and Assessment Core Process	Geological Survey of Ethiopia	2011	Corbetti
Geological Survey of Ethiopia - Proposal for a Prefeasibility Stage Geothermal: Exploration Project in Tendaho Graben	Ministry of Mines and Energy, Ethiopia	2011	Country-wide
Geothermal Development in Ethiopia	Ethiopian Institute of Geological Surveys, Hydrogeology, Engineering geology and Geothermal Department	2010	Country-wide
Preliminary Geological and Fluid Geochemical Study of Geothermal Sites in Somali Regional State (Shinele zone)	Geological Survey of Ethiopia	2009	Shinele Zone
Investment Opportunities in Geothermal Energy Development	Ministry of Mines and Energy, Ethiopia	2008	Tulu Moye
Investment Opportunities in Geothermal Energy Development	Ministry of Mines and Energy, Ethiopia	2008	Tendaho
Investment Opportunities in Geothermal Energy Development	Ministry of Mines and Energy, Ethiopia	2008	Aluto-Langano, Tendaho, Corbetti, Abaya, Tulu, Dofan Fantale

Direct Utilization of Geothermal Resources for Horticulture in Greenhouses: Assessment of Potential Applications in Selected Areas of Ethiopia	Addis Ababa University	2008	Country-wide
Report on Surface Temperature Measurements in Abaya Geothermal Prospect	Ministry of Mines, Ethiopia	2008	Abaya
Investment Opportunities in Geothermal Energy Development – Dofan Fantale Geothermal Prospect	Ministry of Mines and Energy, Ethiopia	2008	Dofan Fantale
Investment Opportunities in Geothermal Energy Development – Corbetti Geothermal Prospect	Ministry of Mines and Energy, Ethiopia	2008	Corbetti
Investment Opportunities in Geothermal Energy Development in Six Selected Geothermal Prospects in Ethiopia	Ministry of Mines and Energy, Ethiopia	2008	Six sites
Investment Opportunities in Geothermal Energy Development – Abaya Geothermal Prospect	Ministry of Mines and Energy, Ethiopia	2008	Abaya
Geological, Surface Hydrothermal Alteration and Geothermal Mapping of Dubti-Semera area, Tendaho Geothermal Field	Hydrogeology, Engineering Geology and Geothermal Department	2006	Country-wide
Preliminary Geochemical Report of Abaya Geothermal Prospect	Geological Survey of Ethiopia	No date	Abaya
Resource Assessment Report	JICA	No date	Aluto Langano
Geothermal Energy in Ethiopia	Cluff Geothermal	No date	Country-wide

Of the 22 sites that were identified for geothermal resources, the top six most promising prospects have been studied in extensive detail, including geology, geochemistry and geophysics. Additionally, conceptual models have been identified where temperature gradient holes, shallow and deep wells existed. One of the notable studies included a 3D numerical modelling of the Aluto Langano geothermal field, giving way to comprehensive feasibility studies. Nevertheless, the studies began in the 1970s and most of the data related to wells requires updating. Additional and focused geophysical data and prefeasibility studies from existent fields are also missing.

2.2.3 Summary of Findings and Geothermal Site Selection

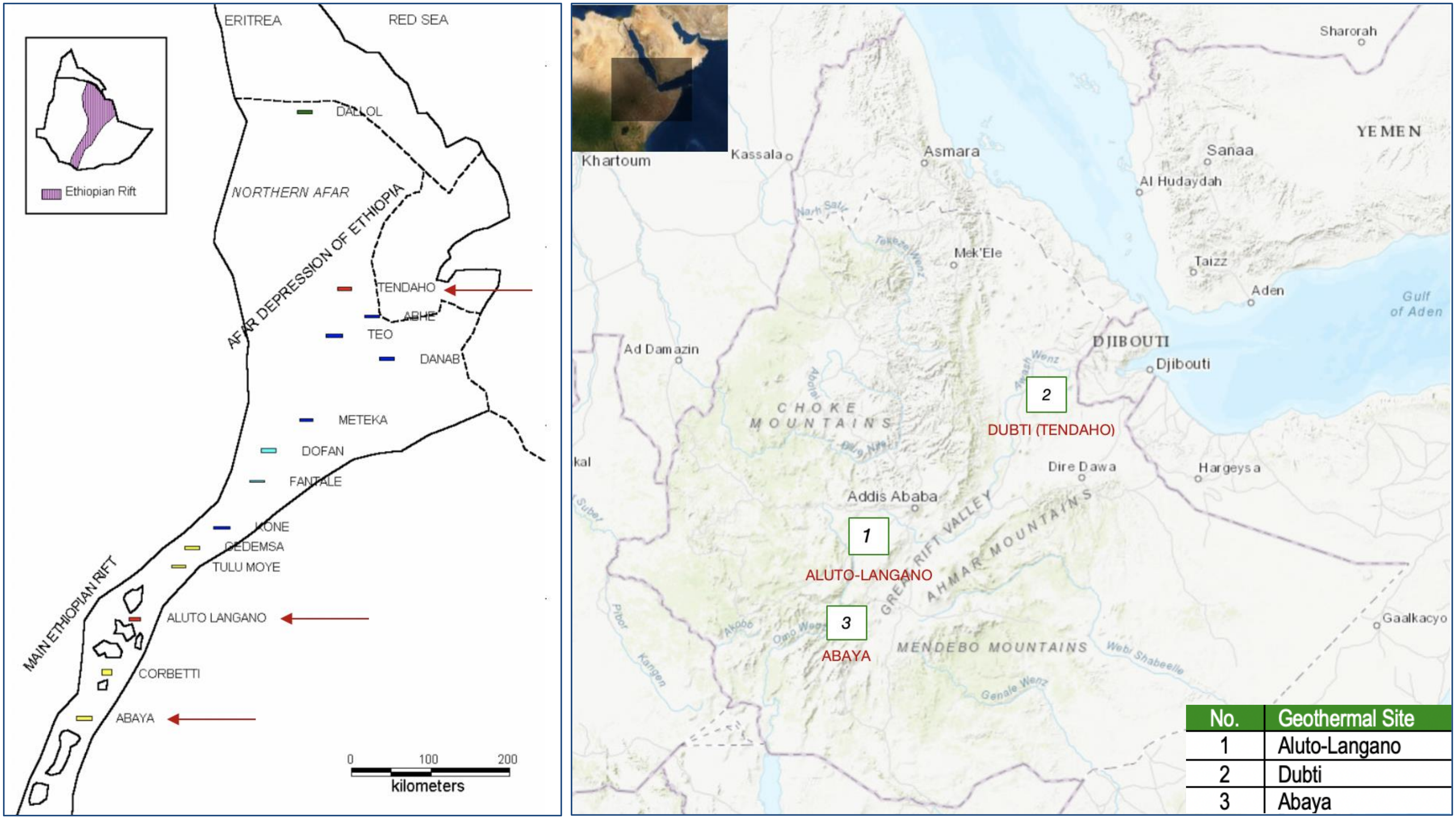
The top three sites identified for Ethiopia are presented in **Table 4** and **Figure 10**.

Table 4: Geothermal Site Selection and Weighted Scoring for Ethiopia

No.	Geothermal Resource	Classification	Classification Score	Project Weighted Score
1	Aluto-Langano	Proven Reserve	44	106
2	Dubti	Proven Reserve	44	38
3	Abaya	Indicated Resource	22	20

Source: GreenMax Capital Advisors analysis

Figure 10: Map of Selected Geothermal Sites in Ethiopia



No.	Geothermal Site
1	Aluto-Langano
2	Dubti
3	Abaya

Source: ARGeo Africa Geothermal Inventory Database; GreenMax Capital Advisors analysis

(1) ALUTO-LANGANO GEOTHERMAL PROSPECT

➢ Geology

Aluto Volcanic Center covers an area of about 100 km^2 between Lakes Langano and Ziway and rises about 690 m above the surrounding Adami - Tullu Plain which has an elevation of about 1,600 masl. Volcanic activity at the Aluto volcanic center was entirely contained in the Quaternary. From the drilled formations the Basalt flows were found to have several flows of coarsely porphyritic lava and breccias with interlayering of rhyolite and pyroclastics which are brecciated and fractured and later sealed by hydrothermal alteration. The hydrothermal mineral assemblage identified in the Aluto-Langano Geothermal wells indicate a high temperature active system which correlates with the present measured temperature range from 220 to 300°C.

An extensive cap rock having large lateral coverage exists at Aluto-Langano in the form of lake sediments and associated overlying pyroclastics. The Aluto-volcanic complex is mainly affected by NNE-SSW trending Wonji Fault Belt. A major fault passes through wells LA-3 and LA-6 extends from Lake Langano (south) and Lake Ziway (north). This fault controls the circulation of the deep geothermal fluid.[38]

➢ Geothermal Manifestations

From Lake Langano (south) and Lake Ziway (north) there are several surface manifestations; fumaroles, hot and warm springs and altered grounds. Hot spring water occurring along the northern shore of the Lake Langano and water sampled shallow from thermal gradient holes drilled in the Aluto-Langano field have essentially similar chemistry with the reservoir water of deep wells. This implies that the spring water and shallow thermal water are derived from the reservoir water. The spring water and borehole water are low in SiO2 and potassium (K) and high in calcium (Ca) and magnesium (Mg) relative to the reservoir water. Those differences in chemistry are thought to result from the lower temperatures in shallow aquifers compared to the deep reservoir (possibly due to boiling and mixing with shallow groundwater).[39]

➢ Geochemistry

The broad truncated base and a summit caldera 6 km by 9 km elongated in a WNW direction has formed a basin of internal drainage. The deep water flows mainly towards the south, southwest and southeast, but also towards the east, supplying the springs and shallow temperature gradient wells and fumaroles at lower and higher elevations, respectively. The partial pressure of carbon dioxide in the field is high, exceeding 30 bars at the reservoir. The thermal water occurring in the Aluto-Langano geothermal field is basically bicarbonate-chloride (HCO3-Cl) type with alkali or neutral pH. In the mixing model, the hottest fluid as a possible parental fluid is assumed to have a temperature around 360º and a Cl concentration around 350 mg/kg.[40]

➢ Geophysics

The geophysical investigations carried out at Aluto include: (a) Gravity Survey; (ii) Electrical resistivity survey; and (iii) Temperature Survey. Geophysical Observatory carried out the earliest gravity survey around Aluto volcano and Lake Langano in the year 1972. Between 1982 and 1985 about 460 gravity readings were taken in Aluto geothermal prospect area. VES Schlumberger resistivity soundings conducted

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[38] "Investment opportunities in geothermal energy development in six selected geothermal prospects in Ethiopia, A Project Profile," Ministry of Mines and Energy, Government of Ethiopia, (2008).

[39] JICS, 2016.

[40] Ibid.

within different parts of Aluto-Langano reflected three-layered resistivity characteristic. The area around the central and southern portions of the resistivity discontinuity and the central portion of the resistivity discontinuity, especially in the uplifted higher resistivity zone detected at depths between 1,000 m and 2,000 m were recommended as promising zones for future drilling targets for production wells based on the results of the geophysical data.[41]

Overall, it can be said that the prospective sites are in the east and southeast part of Aluto volcano. These areas, which are delineated by relatively high resistivity anomalies are the thermal field resources for economic power development. Deep wells LA-3 and LA-4 in the area of geophysical anomaly confirmed the interpretation, since the measured temperatures encountered in the wells are more than 250°C.[42]

- **Thermal Gradient Holes**

Shallow thermal gradient holes (TG-1 up to TG-10) and two deep wells (LA-1 & LA-2) were drilled at the western and eastern foothills of Aluto, and in-hole temperature measurements were taken. The resistivity lows caused by hot geothermal fluid circulations, the occurrence of geothermal manifestations, and comparison of bottom-hole temperatures in the TG wells with the temperature gradient in the deep wells led to the conclusion that the up-flow zone is somewhere under the Aluto-volcanic complex and lateral flows feed the aquifer under the foothills. Additional temperature gradient holes (TG-11 up to TG-29 and TG-36) were drilled to 50-60m depth. Temperature profiles of most holes show isotherm (due to steam) at the interface between shallow pumice layer (20-40m) and shallow rhyolite flow. The highest temperature gradient observed was in the eastern and northeastern parts of Aluto volcanic complex. The drilling of LA-3 led to the discovery of the Aluto geothermal reservoir.[43]

- **Drilled Wells**

In the Aluto-Langano geothermal field, ten deep geothermal wells were drilled with a maximum depth of 2500m. The first eight exploration wells (LA- 1 to LA-8) were drilled between 1981 and 1986 with a maximum depth of 2500m, reaching temperatures of up to 335°C.[44] The following wells (LA-9D and LA-10D) have been drilled to depth of 1920 m and 1951 m respectively. Both wells are productive with bottom hole temperatures of over 300º C. The first 8.5 MW (7.2 MW net) pilot power plant was installed by Ethiopian Electric Power (EEPCo) and connected to the national power grid. It was started by four production wells (LA-3, LA-4, LA-6 and LA-8, and with one reinjection well, LA-7).

- **Conceptual Model**

The geothermal system of the Aluto Langano sector is considered to be a hydrothermal convection system that has been present for a long time. It is recognized that different geological formations are contributing to the storing of geothermal fluids (the Bofa Basalt formation and the Tertiary Ignimbrite formation), but it is believed that those faults are playing the role of the main conduits permitting the high temperature underground fluids to migrate. Aluto-Langano is water dominated gas-rich geothermal field having a reservoir temperature in excess of 360°C as estimated by various geothermometers. In addition, the measured temperatures encountered in the wells were more than 250°C. The hydrothermal system is fed by meteoric water infiltrated in the neighboring lands (mainly from the eastern escarpment of Ethiopian Rift Valley) of the Aluto volcanic complex. Thermally, an up-flow zone beneath wells LA-3, LA-6, LA-9D and

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[41] JICS, 2016.

[42] "Investment opportunities in geothermal energy development in six selected geothermal prospects in Ethiopia, a Project Profile," Ministry of Mines and Energy, Government of Ethiopia, (2008).

[43] Ibid.

[44] Teklemariam, M., and Beyene, K., "Geothermal Exploration and Development in Ethiopia," Proceedings World Geothermal Congress, 2005.

LA-10D, which are located on the WFB fault, characterizes the Aluto Langano geothermal field. This up-flow is comprised of high enthalpy fluid and superheated steam. The geothermal reservoir has high CO2 content. The movement of the deep hot fluids is mainly along the NNE-SSW trending faults (N5, R1 and G2) at the center of the Aluto Langano caldera.

- **Preliminary Assessment**

The Aluto-Langano geothermal prospect has been classified as a "Proven Reserve" and has a very high project weighted score in the analysis.

The Aluto-Langano site has been one of Ethiopia's most heavily assessed geothermal resources and with international financing, supervision and capacity building, a pilot project was launched at the site in 1998, which was a 8.5 MW geothermal power plant. Geological, geochemical and geophysical studies were completed; JICA is leading implementation of the project upgrade and has undertaken a very thorough analysis of well data and conducted conceptual modeling which was then incorporated into a 3D model of the reservoir.

The project subsequently received funding for the next phases of development to increase the geothermal site's capacity to 35 MW and eventual expansion to 75 MW – additional production wells are planned to achieve this expansion. However, in 2016 the plant had to be shut down due to maintenance challenges. In early 2020, EEPCo signed an Engineering, Procurement and Construction contract with three companies to restart the project; 5 MW of new capacity is expected to be commissioned in 2021.[45]

Despite these recent setbacks, the project still represents one of the country's most advanced and confirmed resources and shows promise for direct use applications and/or cascading geothermal technologies.

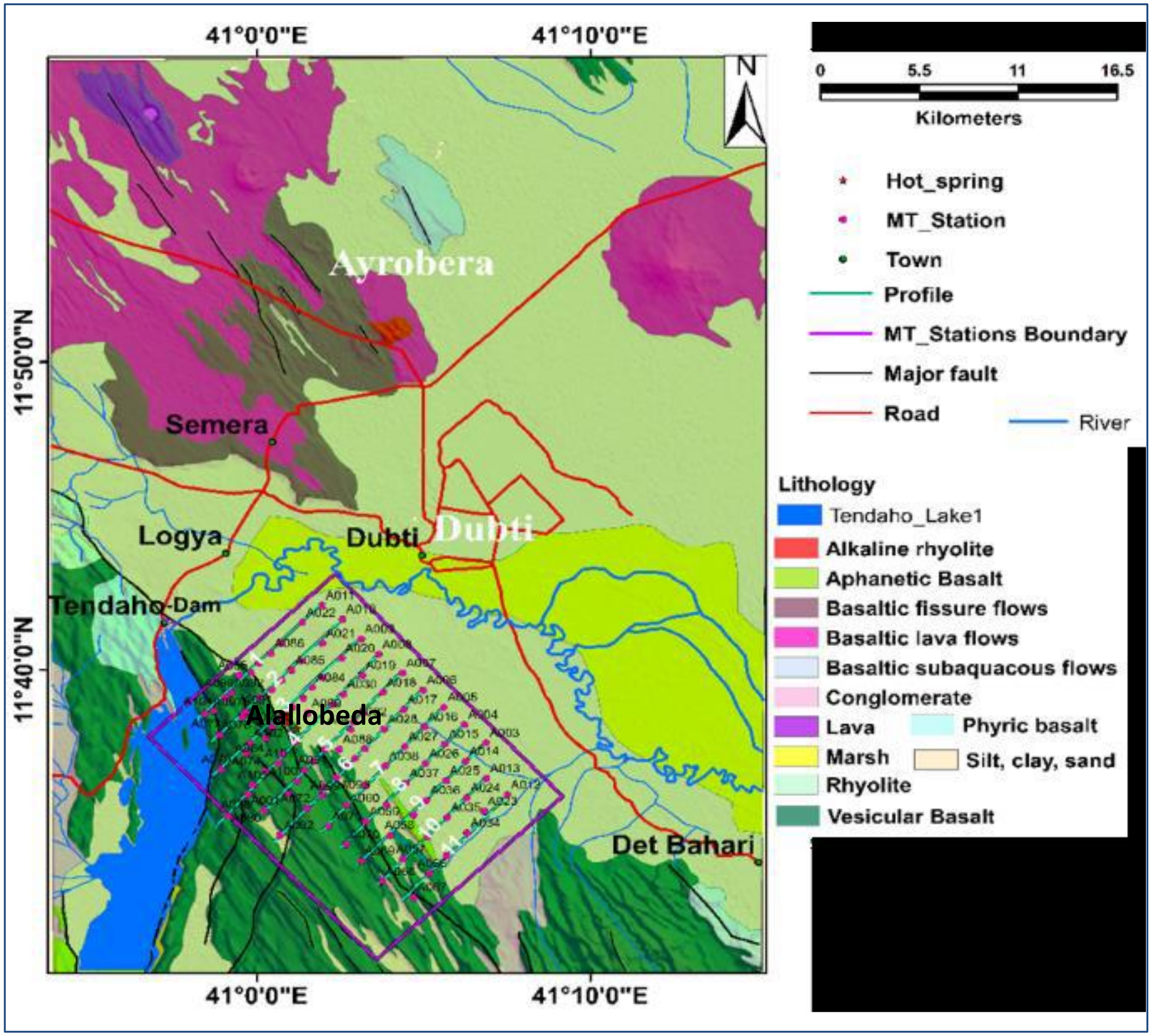
(2) DUBTI GEOTHERMAL PROSPECT

The Dubti geothermal prospect is part of the Greater Tendaho geothermal field located within the Tendaho graben of the Afar rift in the NE part of Ethiopia, about 600 km from Addis Ababa. The Greater Tendaho geothermal area, which is about 1,400 km^2 comprises the following geothermal fields that have been divided to ensure more effective resource exploration and development: Dubti, Allalobeda and Ayrobera (**Figure 11**).[46]

[45] "Ethiopia: EEP signs EPC contract for Aluto Langano Geothermal Power Plant," Africa Energy Portal, (5 March 2020): https://africa-energy-portal.org/news/ethiopia-eep-signs-epc-contract-aluto-langano-geothermal-power-plant

[46] Stimac, J., Armadillo, E., Rizzello, D., and Mandeno, P.E., "Geothermal Resource Assessment of the Tendaho Area: Technical Review Report," UNEP and GSE, (2014).

Figure 11: Map of Dubti Geothermal Prospect (Tendaho Field)



Source: Kebede, 2018

- **Geology**

Tendaho lies within a NW-SE trending graben, part of the southeastern echelon extension on land of the Red Sea rift entering Afar to join the Lakes District and Gulf of Aden rifts at a triple junction located in the graben. Normal and strike-slip faults as well as open fissures characterize the graben.[47]

Dubti is the best studied geothermal area within the Greater Tendaho geothermal area. The geothermal field is located on the northwestern margin of Tendaho Graben and covered by volcanic group (basic to felsic) and sedimentary sequences. The Afar Stratoid Series constitutes the borders of the Tendaho rift and downthrown under the graben floor. The rift is filled with lacustrine and fluvial deposits and with post-Stratoid basaltic flows. On the rift floor are also found recent volcanic products that include scoria cones, fresh Pahoehoe basaltic flows and hyaloclastite deposits. The products of alluvial deposits along River Awash resulted in the formation of various sediments ranging from conglomeratic sand at the bottom part and silt clay deposit in the top part of the succession. The stratigraphy of the Dubti geothermal field developed from drilled wells show the interlayering of volcanic and sedimentary lithologies.

- **Geothermal Manifestations**

Active and fossil surface hydrothermal manifestations characterize the Tendaho-Dubti area, having a general strike of NW-SE direction and extending over a distance of 2.5 km. The manifestations include mud cones, fumaroles, steaming ground, hot springs and hot grounds. Around fumarolic areas occur deposition of Sulphur crystals and hydrogen sulfide gas discharge (rotten egg smell). Maximum temperature measured on the surface at a steam vent was 100.3ºC.[48]

- **Geochemistry**

The system is water dominated and has one or more reservoirs with temperatures exceeding 230°C. Reservoir equilibrium temperatures and CO2 partial pressures of discharges from Dubti shallow geothermal wells, TD1, TD2, and TD4) are 260-278°C (1.3 Mpa), 220-225°C (0.35) and 235-240°C (0.4 +/ 0.1), respectively. The reservoir fluid is NaCl.[49] Liquid and gas samples from Dubti indicate temperatures of 235-250°C in the shallow northern part of the system, and temperatures up to 300°C in a deeper source region to the southeast.[50]

- **Geophysics**

Geophysical techniques deployed for the investigation of Dubti geothermal field include gravity, magnetics, seismic, and MT/TEM. MT/TEM indicates a shallow conductor under Dubti corresponding with the shallow reservoir confirmed by drilling. Microearthquakes shows shallow intense seismic activity that is attenuated at shallow depth under Dubti suggesting the presence of a shallow magma body.

- **Thermal Gradient Hole/Exploratory wells**

Six geothermal wells were drilled in Dubti between 1993 and 1998. The first well (TD1) was drilled to a total depth of 2196m and encountered temperature of more than 278°C but was unable to discharge due to

[47] "Investment opportunities in geothermal energy development in six selected geothermal prospects in Ethiopia, A Project Profile," Ministry of Mines and Energy, Government of Ethiopia, (2008).
[48] Megersa, G. and Getaneh, E., "Geological, Surface Hydrothermal Alteration and Geothermal Mapping of Dubti-Semera area, Tendaho Geothermal Field," Geological Survey of Ethiopia, (2006).
[49] Ibid.
[50] Stimac, J., Armadillo, E., Rizzello, D., and Mandeno, P.E., "Geothermal Resource Assessment of the Tendaho Area: Technical Review Report," UNEP and GSE, (2014).

low permeability. The second well (TD-2) drilled to 1811m encountered maximum temperature of 245ºC and a reversal at bottom of hole but the well is able to discharge. TD-3 drilled to 1989m is non-producer due to poor permeability and low temperature (<200°C). Between 1995-1998, three shallow wells (TD-4, TD-5, and TD-6) were drilled in Dubti to depths of 466-516m) and all encountered temperatures of 245-253ºC and total mass flow rates (38-70 kg/s). Results of drilling indicated that shallow wells are better producers than deep wells. These two wells prove the existence of shallow reservoir characterized by low salinity, low non-condensable gas content and temperature distribution with depth close to a boiling point for depth curve. The shallow reservoir has a power potential of 3-3.5 MW from the drilled well.[51]

- **Conceptual Model**

It is conceptualized that the geothermal system under Dubti originates from a single liquid phase with an initial temperature of ~ 300°C which then ascend vertically along the NW-SE structural fault planes located near the area of thermal manifestations. Once the fluid reaches shallow horizontal permeable zones, it expands and out-flows supplying the manifestations and the wells drilled in the field. The lateral flow is shown by the electrical conductor at intermediate depth. Two geothermal reservoirs have been identified at Dubti with the shallow reservoir having a temperature of 245°C while the deeper reservoir has a temperature of about 270°C-300ºC. The NW-SE fault system have been interpreted to have an important role in controlling the reservoir location and fluid flow trends.

- **Preliminary Assessment**

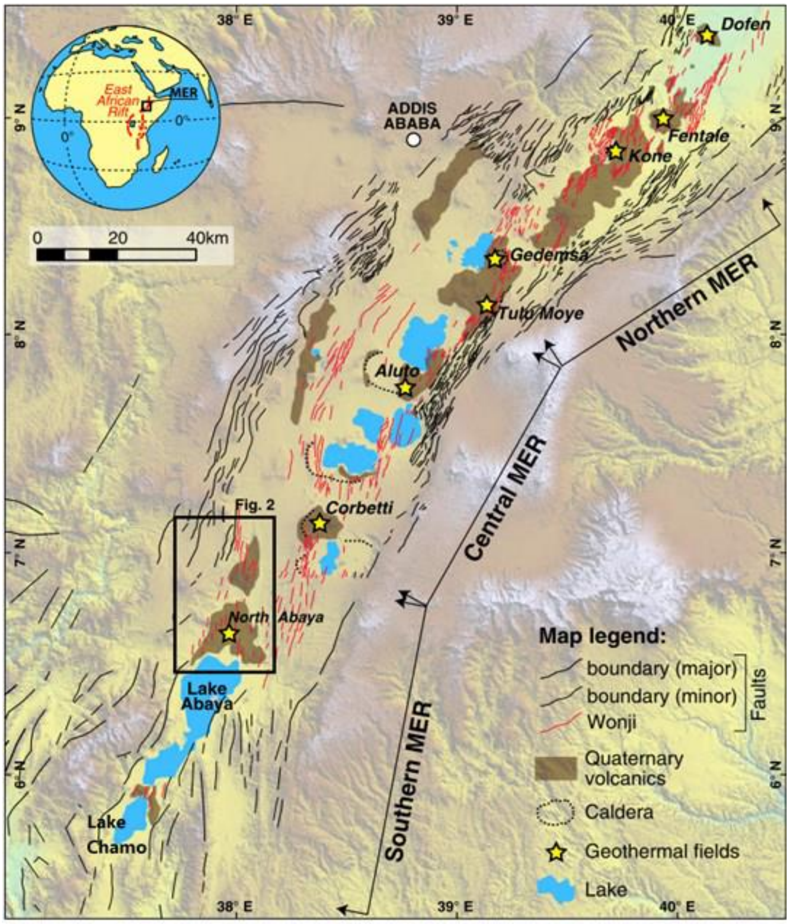
The Dubti geothermal prospect has been classified as a “Proven Reserve” and has a moderately high project weighted score in the analysis.

The Dubti geothermal field is the most promising site within the Tendaho geothermal area. A feasibility study for shallow resource development at Dubti was undertaken with support from AFD to assess the feasibility of development and exploitation of the geothermal resource. The study recommended the exploitation of the proven resource pertaining to the shallow reservoir, through a pilot power plant of installed capacity of up to 12 MW by drilling an additional six shallow wells (Kebede, 2016). Further development of the resource would consider developing the deeper reservoir for large power plant development. In addition, Dubti geothermal field has a high potential for direct use applications including tourism, agriculture and process heat.

[51] Megersa, G. and Getaneh, E., “Geological, Surface Hydrothermal Alteration and Geothermal Mapping of Dubti-Semera area, Tendaho Geothermal Field, Geological Survey of Ethiopia,” (2006).

(3) ABAYA GEOTHERMAL PROSPECT

Figure 12: Map of Abaya Geothermal Prospect



Source: Reykjavík Geothermal

- **Geology**

The Abaya geothermal prospect is the southern-most high temperature geothermal system in Ethiopia. The prospect lies within the axis of the southern main Ethiopian rift, north of Lake Abaya. This segment of the rift is younger than the central and northern MER and exhibits rifting as shown by the absence of rift escarpment. The local geology of the Abaya area consists of igneous and sedimentary lithologies. Most of the rift floor and margins in the area are covered by volcanic and volcano-sedimentary rocks associated with main rifting events. The most recent lithologies in the concession area consist of scoria, basalt, rhyolite, trachyte, ignimbrite, pyroclastic material and alluvium and fluvial deposits. Recent rhyolitic volcanism occurred in the western side of the concession and some of them have been interpreted as calderas. The structural pattern in the area is dominated by NNE-SSW trending fault swarm which is coincident with the structural pattern of the Wonji Fault Belt.[52] Previous studies revealed the presence of NW-SE structures that cut through the dominant NE trending faults. These oblique structures host most of the geothermal manifestations.

[52] Cervantes, C., Eysteinsson, H., Gebrewold, Y., Di Rienzo, D., Guðbrandsson, S., "The Abaya Geothermal Project, SNNPR, Ethiopia," World Geothermal Congress, 2020: https://pangea.stanford.edu/ERE/db/WGC/papers/WGC/2020/12099.pdf

- **Geothermal Manifestations**

Geothermal manifestations are common in the Abaya geothermal area with occurrences of hot springs, fumaroles, and hot grounds which are aligned along the NW Abaya fault. Boiling NaCl hot springs occur in the NW part of the area and discharges at about 96ºC. Other hot springs discharge at temperatures of between 37ºC to 96ºC (Geological Survey of Ethiopia, 2008). Moderate-temperature steaming areas are found at 30-45˚C, and on the northwest Abaya fault boiling mud pools and abundant fumaroles are found with temperatures ranging from 50 – 100˚C.[53] Furthermore, several springs and hydrothermally altered surface rocks with weak fumarolic activity can be found on the northwest Abaya fault.

- **Geochemistry**

The hot spring water show high concentrations of SiO_2, CO_2, and relatively low SO_4 and chlorine and thus plotting as bicarbonate waters. The concentration of sodium in the water samples ranges from 5 to 1370 ppm, potassium 3 to 174 ppm, calcium 0.4 to 53 ppm and magnesium 0.1 to 56 ppm. The Giggenbach ternary diagram and therefore the geothermometers suggests that most of the waters are regarded as immature, or partially equilibrated. Silica geothermometry gives a temperature range of 140-252ºC.[54]

- **Geophysics**

Geophysical studies undertaken in the Abaya geothermal area include magnetics, gravity, MT, and TEM. Results of the study reveal anomalies that are consistent with high temperature geothermal systems. Two low resistivity layers are observed: the first shallow layer at few hundred meters depth to roughly 2 km depth which is interpreted as thermally altered zone of temperatures up to 230°C and the second conductor is found to be at 8 km depth and interpreted as a heat source for the active geothermal system in Abaya.[55]

- **Conceptual Model**

The geothermal system at Abaya is controlled to a large extent by the intersection of NE-SW structural pattern coincident with the Wonji Fault Belt and the NW-SE oblique faults. Fluid geochemistry indicates that a high temperature geothermal system exists in the area driven by magmatic heat source associated with felsic volcanism in the area. The fluid chemistry is bicarbonate rich and probably from a reservoir at more than 230ºC. The reservoir could have a chloride concentration not exceeding 800 mg/l and exist in the liquid dominated phase.[56]

- **Preliminary Assessment**

The Abaya geothermal prospect has been classified as an "Indicated Resource" and has a relatively lower project weighted score in the analysis. Previous studies and conceptual model developed suggest the presence of a high-enthalpy reservoir suitable for geothermal power production in the Abaya area. The western side of the prospect dominated by recent volcanism is considered to have higher potential. It has also been suggested that since the area is agriculturally rich with cash crops such as tobacco, the site's geothermal resources can be used for curing the leaves and other direct use applications.[57]

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[53] Cervantes et al., 2020.
[54] Ibid.
[55] Ibid.
[56] Salahadin, A. and Lemma, K., "Preliminary Geochemical Report of Abaya Geothermal Prospect," Geological Survey of Ethiopia: Hydrogeology, Engineering Geology and Geothermal Department: Geothermal Division, 2008.
[57] Ibid.

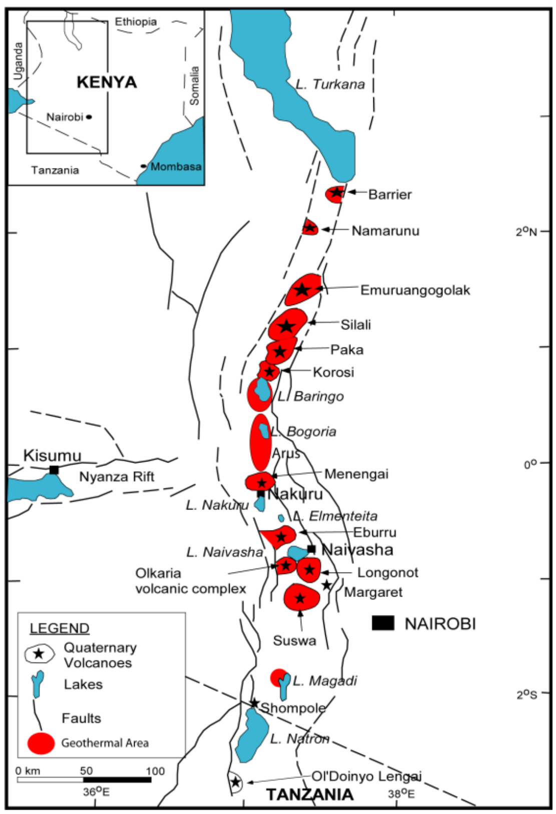
2.3 KENYA

2.3.1 Geothermal Sector Overview

Kenya began developing geothermal sites in the 1950s and commissioned the first geothermal plant in 1981 at the Olkaria geothermal field within the Kenyan rift.[58] As of early 2020, Kenya had 823 MW of installed geothermal capacity, representing about one-third of the country's installed capacity.[59] Of the installed geothermal capacity in 2019, Kenya Electricity Generating Company (KenGen) produces 706.8 MW, OrPower4 Inc produces 155 MW, and Oserian Development Company Ltd. produces 3.6 MW.

Between 2020 and 2022, geothermal power output is projected to increase by 328 MW, as several new power plants come online: the Olkaria KenGen-PPP site will produce 140 MW, the Olkaria 1 site will produce 83.3 MW, and the Menengai geothermal field under development by Geothermal Development Company (GDC) will produce 105 MW. In addition, the government has licensed 13 IPPs to undertake green-field projects at Barrier, Longonot, Akiira, Elementaita, Homa Hills, Menengai North, Lake Magadi, Arus, Baringo, Emuruangogolak, Namarunu, and Emuruapoli. According to licensing conditions, the IPPs are required to drill exploration wells within three years of license issuance.[60]

Figure 13: Map of Geothermal Sites in Kenya



Source: Kenya Geothermal Development Corporation

[58] Mariita, N. O., "Exploration history of Olkaria Geothermal field by use of Geophysics," Presented at Short Course IV on Exploration for Geothermal Resources, organized by UNU-GTP, KenGen and GDC at Lake Naivasha, Kenya, November 1-22, 2009.
[59] Kwame, V., "Kenya geothermal development," The Standard, (14 April 2020): https://www.standardmedia.co.ke/business/article/2001367960/geothermal-kenya-basks-in-ranking-seventh-heaven
[60] Omenda, P. and Mangi, P., 2016. Country update report for Kenya: 2016. Proceedings, 6th African Rift Geothermal Conference Addis Ababa, Ethiopia, 2nd – 4th November 2016.

2.3.2 Summary of Available Data and Gaps in Data

A summary of the data that was available for Kenya is presented in **Table 5**.

Table 5: Summary of Existing Data Available for Kenya

Name of Document/Report	Source	Date (publication)	Name of geothermal site(s)	Notes
Country Update Report for Kenya 2016	KenGen	2016		Overview of Geothermal prospects
Direct Use of Geothermal Energy: Menengai Direct Use Pilot Projects in Kenya	GDC	2016	Menengai Prospect	Direct use in Menengai
Geothermal Exploration of the Menengai Geothermal Field	GDC	2016	Menengai Prospect	Geothermal resource assessment of Menengai
Opportunities for direct utilization of Geothermal Energy in Eburru Area	KenGen	2016	Eburru Prospect	Direct use in Eburru
An Overview of Geochemical Characteristics of Olkaria Geothermal Field, in Kenya	Geothermal Energy Training and Research Institute - Dedan Kimathi University of Technology	2014	Olkaria Prospect	Geochemistry of Olkaria
Structural Geology of Eburru-Badlands Geothermal Prospect	KenGen	2014	Eburru Prospect	Structural Geology of Eburru
Direct Use of Geothermal Energy in Menengai Kenya: Proposed Geothermal Spa and Crop-drying	GDC	2013	Menengai Prospect	Direct Use Applications
Direct Utilization in Kenya: A Case Study of Geothermal SPA and Demonstration Center at Olkaria	KenGen	2013	Olkaria Prospect	Direct Use Applications
Results of Well Production Test for Olkaria Domes Field, Olkaria	KenGen	2012	Olkaria Prospect	Well Geology
Cascaded Use of Geothermal Energy: Eburru Case Study	GDC	2012	Eburru Prospect	

Within East Africa, Kenya has experienced profound geothermal development compared to its neighbors. There exist several hundred wells in the geothermal fields at Olkaria, Eburru and Menengai, which have provided power to the county for several decades. This institutional knowledge has allowed the country to become a leader in geothermal processes, collecting extensive data each year. Kenya continues to study potential sites for direct use opportunities. All available data that was analyzed comes from the three aforementioned sites; therefore, a broader country-based analysis must be completed to better understand Kenya's national direct use potential.

2.3.3 Summary of Findings and Geothermal Site Selection

The top three sites identified for Kenya are presented in **Table 6** and **Figure 14**.

Table 6: Geothermal Site Selection and Weighted Scoring for Kenya

No.	Geothermal Resource	Classification	Classification Score	Project Weighted Score
1	Olkaria	Proven Reserve	56	126
2	Eburru	Proven Reserve	46	106
3	Menengai	Proven Reserve	53	105

Source: GreenMax Capital Advisors analysis

Figure 14: Map of Selected Geothermal Sites in Kenya

Source: ARGeo Africa Geothermal Inventory Database; GreenMax Capital Advisors analysis

(1) OLKARIA

➢ Geology

The Olkaria geothermal site is part of one of the largest geothermal systems in the world, located in a complex geological environment containing various geologic attributes. Development of the Olkaria volcanic area commenced during the Pliocene era with the eruption of flood trachyte and basalt on the floor of the developed rift graben. The area was subsequently grid faulted by the dominant N-S faults while the older NW-SE were reactivated by the changes in the regional stresses. These faults formed the loci for development of a volcanic area occupied by the Olkaria volcanic field. The products of volcanism included basalts, trachytes, rhyolites and their pyroclastic equivalents.[61]

Studies have revealed that whereas the basalts and trachytes could have originated from primary magmas, the comenditic rhyolites originated from crustal anataxis of syentitic precursors followed by protracted differentiation to produce the highly silicic lavas present at Olkaria.[62] The magma chambers associated with these rhyolites are the cause for the discrete heat sources that drives the geothermal system at Olkaria. The Olkaria geothermal area has been divided into seven sectors for ease of development, namely, Olkaria central, Olkaria Domes, Olkaria NE, Olkaria Central, Olkaria west, Olkaria south west, and Olkaria north west. All these sectors have wells drilled to about 3 km and have encountered temperatures of up to 342℃. Structures at Olkaria are dominated by N-S, NW-SE and NE-SW. The intersection of some of these structures has created a ring structure that has been interpreted by some to be a defining trace of a buried caldera structure.

➢ Geothermal Manifestations

The geothermal manifestations at Olkaria comprise hot and uneven ground, fumaroles, steam, sulphur deposits and hot springs. The manifestations commonly occur along structural trends where discharge temperatures are as high as 97℃. Hot springs occur within the Ol'Njorowa gorge in the eastern side of the greater geothermal area within the Domes field. The areas with the most intense geothermal manifestations occur along the Ololbutot fault line where fumaroles have sulphur encrustations.

➢ Geochemistry

More than 300 deep wells have been drilled in the Greater Olkaria geothermal area and of these, more than 250 are productive. Analysis of the discharged fluids indicate that the reservoir fluids at Olkaria vary from NaCl neutral fluids to $NaHCO_3$. The Olkaria central and NE fields are dominantly NaCl while Olkaria Domes straddle between NaCl and $NaHCO_3$. Olkaria west fluids on the other hand are strongly $NaHCO_3$ which has been attributed to injection of mantle CO_2 into the geothermal reservoir. Solute and gas geothermometers indicate source reservoirs at temperatures of more than 250℃. The maximum measured temperature was 342℃ at 3 km depth.

➢ Geophysics

The Olkaria geothermal system has been explored using various geophysical techniques include MT, TEM, Vertical Electronical Sounding (VES) Schlumberger resistivity, gravity, magnetic, and seismic. Latest investigations at Olkaria have involved the use of MT and TEM due to their ease of deployment and the

[61] Omenda, P. A. "The geology and structural controls of the Olkaria geothermal system, Kenya," Geothermics, Volume 27, Issue 1, February 1998, pp. 55-74.
[62] Omenda P.A., "Anatectic origin for Comendite in Olkaria geothermal field, Kenya Rift; Geochemical evidence for syenitic protholith," African Journal of Science and Technology, Science and Engineering series, 1, 2000, pp. 39-47.

greater depth of penetration of the latter. Combined MT and TEM models are more effective in characterizing the conductivity from near surface to deeper levels. MT/TEM when imaging together, provide good resolution of the subsurface electrical conductivity to depths of up to 6 km. Resistivity data interpretation from the Olkaria geothermal field shows that the low resistivity (less than 20 Ωm) anomalies at depths of 1,000 meters above sea level (masl) that define the geothermal resource boundaries are controlled by linear structures in the NE-SW and NW-SE directions. The near surface difference in resistivity is caused by contrasts in the subsurface geology. Drilled wells show that the low resistivity anomalies at 1,000 masl define a geothermal system with temperatures in excess of 240℃. Micro-earthquake studies undertaken in the area shows a zone of seismic attenuation occurring at about 4 km which has been interpreted as the top of a magma body.[63] Gravity shows an anomaly under the geothermal areas that has been inferred to represent the magma body.

- **Monitoring Wells**

Three wells were drilled to a 600 m depth at Olkaria II for monitoring the water level with production of the reservoirs.

- **Conceptual Model**

The conceptual model of the Olkaria geothermal system is defined by partially molten discrete rhyolitic magma chambers that underlie the volcanic centers at about 4-6 km depth. The heat from the shallow magma bodies generates a convective cell with main recharge for the system coming from the Mau escarpment in the west and the Aberdare Mountains in the east with some axial flow. The reservoir is hosted within fractured formations within 1-3 km depth at temperatures of more than 250℃ and is dominated by neutral NaCl fluids. However, the west field reservoir is predominantly bicarbonate due to CO_2 that comes up from the mantle through the deep-seated listric faults in the western rift boundary.

- **Preliminary Assessment**

The Olkaria geothermal site has been classified as a “Proven Reserve” and has a very high project weighted score in the analysis.

Olkaria is a high temperature geothermal system with current power plant generation of 865 MW with the system distributed throughout the entire field. In addition to power generation, direct utilization of geothermal resources has been deployed at Olkaria to provide heat for greenhouses – Oserian, one of the largest fair-trade flower farms in the country, has a 200-hectare site on Lake Naivasha where it produces and exports flowers by using geothermal steam from the Olkaria field.[64] KenGen has also developed a direct use facility from the cascading of brine from the Olkaria II steam-field for spas and hot baths.[65] In addition, the company is considering developing an industrial park adjacent to the field that will use heat and electricity produced from the geothermal field for the various industrial manufacturing projects. Therefore, this geothermal field is recommended for direct use applications in addition to the current indirect use applications.

[63] Simiyu, S.M., 2006. Geothermal reservoir characterization: Application of micro-seismicity and seismic wave properties at Olkaria, Kenya rift. Journal of Geophysical Research, Volume105, Issue B6, 10 June 2000, pp. 13779-13795.
[64] “Field of steam: How Kenya has become a geothermal superpower,” CNN, (December 14, 2016): https://www.cnn.com/2016/12/14/africa/kenya-geothermal-olkaria/index.html
[65] Mangi, P., “Direct utilization in Kenya: A case of a geothermal spa and demonstration centre at Olkaria,” Presented at Short Course VIII on Exploration for Geothermal Resources, organized by UNU-GTP, KenGen and GDC, at Lake Bogoria and Lake Naivasha, Kenya, Oct. 31 – Nov. 22, 2013.

(2) EBURRU GEOTHERMAL FIELD

➢ Geology

The Eburru volcanic complex is located within the Kenya rift valley about 60 km north of the Olkaria Geothermal field comprising of two volcanoes titled: east and west. The older west volcano is built largely of trachytes and rhyolites and draped by thick pumice fall; however, there is no geothermal activity associated with the western volcano. The east volcano is built of trachyte and pantellerite lava flows along an alignment known as the "peralkaline belt" that trends NNE-SSW. This region is the most tectonically and volcanically active part of the Eburru volcanic complex with the youngest peralkaline flow on the slopes of Eburru massif dating at about 26,000 years BP. The earliest activity at Eburru is estimated to have occurred about 500,000 years BP associated with a ring structure at the summit of the volcano.[66] North of Eburru, within the Elmenteita volcanic field, basalt and trachy-basaltic lavas dominate. Wells drilled at Eburru have shown a stratigraphy consisting of basalts, trachytes, rhyolites and their associated pyroclastics. At a depth of 2.7 km below the surface, there is a syenite body that has been interpreted as roof rocks of the paleo magma chamber under the volcano. It has been modeled that the observed rocks at Eburru evolved through protracted differentiation to produce the highly evolved pantellerites.[67]

➢ Geothermal Manifestations

The manifestations common to the area include fumaroles, steaming grounds, steam vents, hot grounds and altered grounds. These manifestations predominantly occur within the area referred to as the "peralkaline belt." Eburru exhibits one of the most active geothermal manifestations in Kenya. Due to water scarcity in the area, communities condense potable water using rudimentary condensation techniques. This provided the main source of water to the community until 1989 when piped water became available. The fumaroles discharge primarily along the fracture systems that are exposed on the northern slopes of the volcano.

➢ Geochemistry

Six wells have been drilled at Eburru. Discharge fluid chemistry from the wells indicates that the reservoir is non-boiling with high salinity brine and a high amount of non-condensable gases (NCG). Despite the almost similar geology, the chloride level of EW-1 (956 to 1,976 ppm) is higher than the Olkaria average. The maximum reservoir temperature measured was 285°C for the reservoir accessed by well EW-01.

➢ Geophysics

Geophysical techniques used to evaluate the Eburru geothermal system comprise of gravity, MT/TEM, and VES Schlumberger resistivity. Gravity data of Eburru shows a high gravity anomaly under the volcano which has been interpreted as the paleo magma chamber. Resistivity measurements using MT and TEM techniques have imaged a conductor under the volcano constrained by the ring structure.[68] A shallow conductor shows a strong extension to the north corresponding to geothermal outflow features.

[66] Kubai, R. and Kandie, R. 2014. Structural geology of Eburru-Badlands Geothermal Prospect. Proceedings 5th African Rift geothermal Conference, Arusha, Tanzania, 29-31 October 2014.

[67] Ren, M., Omenda, P.A., Anthony, E.Y., White, J.C., Macdonald, R., Bailey, D.K., 2001. Application of the QUILF thermobarometer to the peralkaline trachytes and pantellerites of the Eburru volcanic complex, East African Rift, Kenya, Lithos (2001).

[68] Mwangi, A.W., 2012. Eburru Geothermal Prospect, Kenya – Joint 1D inversion of MT and TEM Data. Proceedings, Thirty-Seventh Workshop on Geothermal Reservoir Engineering, Stanford University. Stanford, California, January 30 - February 1, 2012.

- **Monitoring Wells**

No monitoring wells have been drilled in the field.

- **Conceptual Model**

The geothermal system at Eburru is driven by a heat source associated with a syenitic intrusion. The intrusion represents a cooling magma chamber intercepted in well EW-01 at about 2,700m depth. The reservoir is confined by a ring structure that occurs at the summit of the volcano. The geothermal system recharges primarily from meteoric waters from the Mau escarpment. Directly under the eastern volcano there is an upflow constrained by the ring structure. Outflows occur largely to the north, north east, and to a lesser extent to the south through the young rift floor faults that are common in the area. The large fumarolic fields to the north of Eburru are due to shallow steam heated waters discharging through fractures.

- **Preliminary Assessment**

The Eburru geothermal site has been classified as a "Proven Reserve" and has a very high project weighted score in the analysis.

Eburru is a high temperature geothermal system with current power generation of 2.4 MW from a condensing pilot plant constructed and commissioned in 2011. Eburru is a high temperature geothermal system which has two distinct reservoirs that can be developed separately. The deep reservoir under the summit volcano is predominantly high temperature and suitable for flash and binary power generation. The shallow reservoir is predominantly a steam and low-pressure reservoir suitable for binary power generation and/or direct use applications. The deep well drilled to 2.9 km at the summit of the volcano is currently being used for flash power generation while the low-pressure reservoir has been accessed by a well drilled to about 300m. The low-pressure well currently runs a grain dryer and condenses potable water.[69] Therefore, this geothermal field is recommended for further direct use developments.

(3) MENENGAI GEOTHERMAL FIELD

- **Geology**

Menengai is one of the largest caldera volcanoes in the axis of the Kenya rift. The volcano, which is located within the central segment of the rift, started developing around 200,000 years BP. The volcano is composed of a lava shield dominated by trachytic lavas and pyroclastics. Due to ongoing volcanic activity, the caldera collapsed about 30,000 years BP. The floor of the collapse has experienced subsequent volcanic activity. The resurgent dome in the Menengai volcano has the most potential for geothermal development. The resurgent activity was dominated by trachyte and panetellerite volcanism.[70] Fault structures in Menengai trend NE in the southern part of the volcano but then bifurcates, trending to the NW-SE and NE-SW from the caldera floor. The NW trend follows the Molo tectono-volcanic axis while the NE trend follows the Solai graben. The general trend of many structures within Menengai field is N-S, NNE-SSW and NNW-SSE. The NNE-SSW normal fault forms the Solai half graben, these structures are younger than the caldera and cut through the caldera rim in the northeast. The N-S and NNW-SSE structures are older than the NNE-SSW faults and constitute the Molo graben to the north of caldera.

[69] Ndetei. C., 2016. Opportunities for direct utilization of geothermal energy in Eburru area, Nakuru County, Kenya. Proceedings, 6th African Rift Geothermal Conference Addis Ababa, Ethiopia, 2nd – 4th November 2016.
Mburu, M. and Kinyanjui, S., 2011. Cascaded use of geothermal energy: Eburru case study. Geothermal Resources Council Transactions, Volume 35.

[70] Mibei, G., Njue, L. and Ndongoli, C., 2016. Geothermal exploration of the Menengai Geothermal field. Proceedings, 6th African Rift Geothermal Conference, Addis Ababa, Ethiopia, 2nd – 4th November 2016.

- **Geothermal Manifestations**

Geothermal manifestations in Menengai and the surrounding areas occur in form of hot grounds, steaming grounds, altered grounds and fumaroles. These manifestations are confined within the caldera floor, tectono-volcanic axis and faults. The Menengai-Ol Banita area has a number of scattered areas of geothermal activity mainly associated with the N-S faults. The fumaroles within the caldera floor discharge at more than 97°C while those outside of the caldera to the north discharge at lower temperatures. Most of the water boreholes drilled in the Ol'rongai area produce hot water attesting to the local geothermal system.

- **Geochemistry**

Exploration drilling commenced in Menengai in 2011 and currently has over 50 deep wells of depths varying from 2,100 m to 3,200 m. Most wells in Menengai discharge two phase (liquid and vapor) fluids, however, several wells discharge dry steam. The wells at the summit are steam dominated reservoirs. Away from the summit, the geothermal fluids are mostly two-phase. Reservoir fluids in Menengai show relatively high non-condensable gas contributed almost entirely by CO_2. This has the potential to cause scaling in the reservoir and surface equipment.

- **Geophysics**

The geophysical methods used to investigate the geothermal system at Menengai included MT/TEM, gravity, and seismic techniques. Resistivity Cross sectioning through the center of Menengai caldera shows a thin high resistivity (> 100 ohm-m) top layer on fresh fractured lavas. It is underlain by a thick low resistivity (30 -70 ohm-m) layer defined as the reservoir zone. Gravity is high at the center of the caldera confined by gravity lows to the north, east and south. In a regional sense, the entire caldera presents a low gravity anomaly. Micro seismic studies show a spread of intense, small and shallower micro-seismic activity within the caldera floor and in the north at Ol'rongai. The events are attenuated at about 4 km indicating a seismic boundary below which molten magma occurs. Drilling intersected magma bodies at depths of about 2.3 km in the summit area.

- **Monitoring Wells**

Monitoring wells drilled in Menengai geothermal field within the caldera floor are shallow (<300 m) and all contain cold water. In the north, within an area known as Ol'rongai, most of the water boreholes drilled to >200m encountered steam and hot water. This has been used to indicate the presence of geothermal reservoirs in the Ol'rongai area of Menengai geothermal field.

- **Conceptual Model**

Menengai geothermal system can be explained by a magmatic heat source associated with the resurgent volcanism within the caldera floor. The magma that lies at about 3 km has been encountered by several wells drilled within the caldera. The recharge is mainly from the eastern escarpments and also from the rift axial flow. Upflow is mainly within the caldera floor controlled mainly by fault structures. Because of the presence of a shallow magma body, the reservoir fluid is predominantly bicarbonate rich with temperatures of up to 400°C at the well bottom. The outflow is mainly to the north.

- **Preliminary Assessment**

The Menengai geothermal site has been classified as a "Proven Reserve" and has a very high project weighted score in the analysis.

Menengai is a high temperature geothermal field that is being developed primarily for power generation using flash technology. Currently, 105 MW is under development. GDC has further developed direct use pilot projects at Menengai for milk pasteurization, aquaculture, greenhousing and grain drying.[71] GDC also plans to develop a heat park adjacent to the production field and invite the private sector to setup factories using geothermal heat. Overall, the reserve capacity and the GDC's interest in direct use applications are suitable for further development.

[71] Nyambura, E., "Direct use of geothermal energy: Menengai direct use pilot projects in Kenya," Proceedings, 6th African Rift Geothermal Conference, Addis Ababa, Ethiopia, 2nd – 4th November 2016.

2.4 RWANDA

2.4.1 Geothermal Sector Overview

Geothermal investigations in Rwanda begin in the 1980's. The existence of geothermal resources in the identified geothermal prospects has yet to be confirmed. Several reports exist, indicating two areas as prospective zones for geothermal energy; the first zone (Gisenyi, Karisimbi, Lake Karago and Kinigi) in the north-western region associated with volcanoes, and the second zone (Bugarama) in the southern region associated with faults in the East African Rift (**Figure 15**).

Figure 15: Map of Geothermal Sites in Uganda[72]

Source: Fridriksson et al., 2014

Studies conclude that a high-temperature geothermal system (>200°C) may exist on the southern slopes of the Karisimbi volcano and that a medium-temperature geothermal system may exist around Lake Karago (150-200°C).[73] In 2013-2014, two exploration wells were drilled in the southern slopes of the Karisimbi volcano to 3,015 and 1,367 m depth, respectively. Alteration mineralogy and measured temperatures in the two wells are consistent with the normal continental geothermal gradient (i.e. ~30°C/km) conclusively demonstrating that there is not a geothermal reservoir under the southern slopes of Karisimbi.[74]

A JICA study found that the total geothermal resource potential of the selected five fields (Bugarama, Kinigi, Karago, Gisenyi and Iriba) was estimated to be about 47.3 MW at the 80% confidence level, and

[72] Fridriksson et al, 2014.

[73] Egbert, J, Gloaguen, R., Wameyo, P., Ármannsson, H. and Hernández-Pérez, P.A. "Geothermal Potential Assessment in the Virunga Geothermal Prospect, Northern Rwanda". Report Geotherm I. Federal Institute for Geosciences and Natural Resources (BGR), 108 p. (2009)

[74] Rutagarama, U. "Geothermal Resource Exploration in Rwanda: A Country Update", Proceedings, 7th African Rift Geothermal Conference Kigali, Rwanda, 2018.

89.5 MW at the 50 % confidence level.[75] Of the five, Kinigi was evaluated to be the field with highest priority (for a 10 MW+) for detailed investigation and development, because an obvious low-resistivity structure was detected. The geothermal resource potential of the Bugarama area, also characterized by a low-resistivity structure, was estimated to be higher than that of Gisenyi, Karago and Iriba.

2.4.2 Summary of Available Data and Gaps in Data

A summary of the data that was available for Rwanda is presented in **Table 7**.

Table 7: Summary of Existing Data Available for Rwanda

Name of Document/Report	Source	Date (publication)	Name of geothermal site(s)	Notes
Seasonal Agricultural Survey, Annual Report	National Institute of Statistics, Rwanda	2019	N/A	
Review of Geological Studies in the Geothermal Prospect of Bugarama	Energy Development Corporation Limited	2018	Bugarama (Rusizi District)	
Seasonal Agricultural Survey	National Institute of Statistics, Rwanda	2018	N/A	
Agricultural Household Survey	National Institute of Statistics, Rwanda	2018	N/A	
Geology Report for Geothermal Consultancy Services "Study in support of developing geothermal resources at Rubavu-Kalisimbi"	Kenya GDC	2017	Gisenyi, Rubavu District	These four reports summarize the findings of surface geoscientific surveys and geophysical surveys aimed at investigating the geothermal resource potential of the vast Rubavu-Kalisimbi prospect. The target areas of focus were identified after structural mapping and geological investigations coupled with extensive review of previous studies. Results from the geoscientific studies reveal the presence of an intermediate-temperature liquid dominated reservoir hosted in basement rocks at the Kilwa Peninsula controlled by the Kilwa fault system. The reservoir temperature is estimated to be 160°C at an approximate depth of 2,000 m. Shallow parts of
Geochemical Survey Report for Geothermal Consultancy Services "Study in support of developing geothermal resources at Rubavu-Kalisimbi"	Kenya GDC	2017	Gisenyi, Rubavu District	
Geophysical Survey Report for Geothermal Consultancy Services "Study in support of developing geothermal resources at Rubavu-Kalisimbi"	Kenya GDC	2017	Gisenyi, Rubavu District	

[75] Japan International Cooperation Agency (JICA) "Final Report: The project for preparation of electricity development plan for sustainable geothermal energy development in Rwanda (Electricity Development Plan and Geothermal Study)", 2016.

Conceptual Model Report for Geothermal Consultancy Services "Study in support of developing geothermal resources at Rubavu-Kalisimbi"	Kenya GDC	2017	Gisenyi, Rubavu District	reservoir at depths of 800 ± 200 m may host fluids of >100°C. The area is characterized by $NaHCO_3$ hot springs with outlet temperature of 70 ± 2 °C and a flow rate of 2 to 5 l/s acting as the outflow of the system. The heat source of the system is postulated to be deep-seated magmatic dykes that may be associated with the Nyiragongo-Kivu rift tectonic axis.
Final Report: The project for preparation of electricity development plan for sustainable geothermal energy development in Rwanda (Electricity Development Plan and Geothermal Study)	JICA	2016	Gisenyi (Rubavu District); Bugarama (Rusizi District)	The Government of Rwanda requested the government of Japan on this Project for the Preparation of an Electricity Development Plan for Sustainable Geothermal Energy Development and its integration into the Electricity Master Plan.
Use of Geothermal Resources for Drying of Agricultural Commodities in East Africa-Rwanda Report	Gissurarson & Georgsson	2015	Country-wide	The report suggests possible projects that can be considered if sufficient energy and volume of geothermal fluids can be provided.
Comprehensive food security and vulnerability analysis	National Institute of Statistics, Rwanda	2015	N/A	
Baseline Report on the Rwanda Horticulture Organizations Survey	EU	2014	N/A	
Preliminary Feasibility Analysis on the Direct Use of Geothermal Energy in Rwanda: Case Study Gisenyi Hot Spring	KTH School of Industrial Engineering and Management	2014	Gisenyi, Rubavu District	
Surface Exploration Report for Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC	Government of Rwanda	2014	Bugarama (Rusizi District)	The purpose of the project was to conduct surface exploration studies to establish a clear scientific understanding of the geothermal potential in three specific areas namely Bugarama in Rwanda, Ruhwa in Burundi and a third site in DRC to be recommended by the consultant. The geothermal springs in Bugarama and Ruhwa were known geothermal areas prior to the study and are easily accessible. The Bugarama geothermal prospect is located in the Bugarama Graben, a narrow N-S to NE-SW trending valley, one of the northernmost graben south of Lake Kivu. The well-known warm
Temperature Gradient Drilling Report for Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC	Government of Rwanda	2014	Bugarama (Rusizi District)	
Conceptual Model Report for Regional Project for Geothermal Exploration in	Government of Rwanda	2014	Bugarama (Rusizi District)	

Rwanda, Burundi and DRC				springs of Bugarama rise at the foot of the western escarpment of the Bugarama Graben that denotes the fault most intensely on a 100 m long line along the western shore of a small pond fed by the several 45-55 °C warm springs, with extensive gas flow, located at the bottom of the pool The total water discharge from the pond is 20 – 30 L/s. Geochemical analysis suggests that the reservoir temperature is between 65 - 70 °C and the waters taken east of the pond, in a small pool, show even lower temperatures of 50 -55 °C.
Geoscientific Surveys of the Rwandan Kalisimbi, Gisenyi and Kinigi Geothermal Prospects	Shalev et al.	2012	NW geothermal prospects (e.g. Gisenyi); Rubavu District; Nyabihu District	The survey field work started in October 2011 with the MT/TEM, seismic and environmental surveys. Heat flow and geology field surveys began in November 2011 and a CSAMT survey was done in December 2011. A total of 10 MT and 2 TEM instruments were used for 8 weeks to record at 160 stations both MT and TEM data. The challenging electrical measurement conditions necessitated the collection of MT measurements at c. 300 sites in order to reach the goal of 160 stations with high quality data. In addition, CSAMT results were proving to be unsatisfactory; therefore, only 10 km of the proposed 20 km CSAMT lines were recorded. Twelve seismic stations were installed in the first ten days of the field campaign, concentrated in the Kalisimbi and Gisenyi prospects. Several of the seismic stations were moved after six to eight weeks, three stations to the Kinigi area and three to locations closer to the recorded seismic events. The seismic stations were moved at the end of January 2012 after 15 weeks of recording. Due to significant man-made noise during the daylight hours, the effective daily seismic recording time was during 12 night-time hours. Heat flow measurements included drilling of 62 three-m deep holes with sensors at three, two, and one m depths,

				and c. 56 temperature readings in one m deep holes. All readings were made 24 hours after insertion.
Geothermal Potential Assessment in the Virunga Geothermal Prospect, Northern Rwanda (Geotherm I Programme)	Jolie et al.	2009	NW geothermal prospects (e.g. Gisenyi); Rubavu District; Nyabihu District	This work presents the results of a detailed regional geothermal assessment which started in November 2007 as a joint project between the Rwandan government and the German government through the Federal Institute for Geo-sciences and Natural Resources (BGR) on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ). In the framework of the GEOTHERM Programme a detailed structural analysis, a geochemical sampling campaign, a geophysical reconnaissance survey and the mapping of diffuse soil degassing structures have been carried out.

Several studies have been completed in Rwanda since the 1980's. Currently, the experience in Karisimbi with no geothermal resource outcome has revealed that more detailed geology, geochemistry, and geophysics studies are needed and should be adapted to an enhanced conceptual model. The other sites – Bugarama, Gisenyi and Kinigi – also need to be developed in terms of data. Not only geoscientific surveys but also detailed temperature gradient holes and slimhole wells should be completed. Additionally, nationwide surveys should be conducted in order to analyze the country in general; small-scale studies are needed especially for geology, geochemistry, and geophysics.

2.4.3 Summary of Findings and Geothermal Site Selection

The top three sites identified for Rwanda are presented in **Table 8** and **Figure 16**. Taking into account that Karisimbi is on hold, the analysis focuses on other possible alternatives that can be assessed from the available data.

Table 8: Geothermal Site Selection and Weighted Scoring for Rwanda

No.	Geothermal Resource	Classification	Classification Score	Project Weighted Score
1	Bugarama	Inferred Resource	15	16
2	Gisenyi	Inferred Resource	14	15
3	Karago	Inferred Resource	10	9

Source: GreenMax Capital Advisors analysis

Figure 16: Map of Selected Geothermal Sites in Rwanda

Source: ARGeo Africa Geothermal Inventory Database; GreenMax Capital Advisors analysis

2.4.4 Summary of Findings and Geothermal Site Selection

(1) BUGARAMA GEOTHERMAL PROSPECT

➢ **Geology**

The geothermal prospect in the southwest field is controlled by the faulting of the western branch of the East African rift system. The Bugarama prospect is located in the Rubyiro River valley, approximately 13 km southeast of the town of Cyangugu. This valley appears to be a graben, which is a block of down-dropped rock bounded by normal faults.[76] The Bugarama area consists of a Proterozoic basement complex and Cenozoic volcanic rock, but no strato-volcanos and no crater cones have been observed, unlike in the northwestern part of Rwanda. The depression with continuous lineaments in the northern part of this area (Lake Kivu) corresponds to the Western Rift of EARS.

Four main geological units are observed in the Bugarama geothermal prospect: Precambrian metasediments, limestone rocks, Mio-Pliocene volcanic rocks and Quaternary sediments.[77] The dominating feature is the SW-NE trending fissure/fault swarm marking the western escarpment of the Bugarama graben which is an extension of the Ruzisi graben of the EARS. West of the fissure swarm are the Proterozoic metamorphosed formations, whereas the graben floor in the east is made of thick Quaternary Kivu basalts

[76] JICA, 2016.

[77] Turinimana, E., "Review of Geological Studies in the Geothermal Prospect of Bugarama Proceedings, 7th African Rift Geothermal Conference Kigali, Rwanda," 2018.

under a cover of alluvial sediments. These Basaltic lavas are affected by N-S striking normal faults that are inherited from Late Burundian shear faults. These shear faults have been reactivated in dip-slip deformation during the EARS tectonic stage.[78]

- **Geothermal Manifestations**

The manifestations are hot and warm springs and travertine deposits, currently being mined as feedstock for a nearby cement factory. The hot springs flow out along the western edge of the graben as dilute Na-HCO_3 water with temperatures up to 50°C. The hot springs form a large pool on top of the travertine deposit. Flow rates are estimated to be greater than 50 l/s, and the influx is accompanied by a large quantity of gas. The higher temperature vents along the shores of the pool deposit reddish-brown iron oxide.[79] The Bugarama springs are clearly controlled by the Bugarama fissure swarm, which forms a permeable channel from depth to the surface. Close to the Bugarama springs the sediments are covered with travertine deposits from the geothermal water. At the foot of the western escarpment of the Bugarama Graben, which denotes the fault most sharply, there are several 45-55ºC warm springs feeding into a small pond along a 100m line on the western shore, with extensive gas flow located at the bottom of the pond. The total water discharge from the pond is 20-30 L/s.[80]

- **Geochemistry**

A thorough study of the collected water samples indicates that equilibrium is not in place, and therefore the chalcedony geothermometer is the most reliable one, indicating a resource temperature about or below 100 °C. Geochemical analysis suggests that the reservoir temperature is between 65-70 ˚C.[81] The Bugarama hot springs are of neutral HCO3 type and the components of the major cations are Na+K.[82]

- **Geophysics**

The magnetic survey showed some geological lineaments in Bugarama, possibly faults or dykes that may be related to the geothermal surface manifestations. They have NNE-SSW and EW directions. A total of 28 Transient Electro-Magnetic (TEM) soundings were measured in Bugarama, Rwanda. The low resistivity anomalies by the fault extend towards the east of the fault as shown on the resistivity maps. This may indicate that the upflow of geothermal fluid is mainly along parts of the fault, and there may also be outflow into sediments and or along EW fracture systems.[83]

- **Thermal Gradient Holes**

Under the geothermal gradient survey, six wells were drilled in Bugarama. A temperature gradient was only extractable from two of the wells (TG-04: 20.8 and TG-06: 46.5 °C/km). The warm groundwater flow is dominated by an outflow from the fault zone of the escarpment, more of a horizontal flow than an upflow. This leads to lower temperatures farther from the escarpment, both horizontally from the aquifers feeding the springs as well as from buried faults. Here the temperature increases faster with depth, hence a higher

[78] Gislason, G., "Reykyavik Geothermal, Conceptual Model Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC," Report No.: 13006-08, 2016.
[79] JICA, 2016.
[80] Mamo, T., Gislason, G., and Guðbrandsson, S., "Temperature Gradient Drilling Report for Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC," Report No.: 13006-07, 2016.
[81] Ibid.
[82] JICA, 2016.
[83] Gislason, G., Eysteinsson, H., Gudbrandsson, S., Sigurbjorn, J. and Jonsson, J.O., "Surface Exploration Report, Regional Project for Geothermal Exploration in Rwanda, Burundi and DRC," Report No.: 13006, 2014.

gradient. Bugarama was the first field to be drilled, and the progress was far from the best conditions for gradient survey. Due to these conditions the goal of three reliable gradients was not reached, but the interpretation is in accordance with the conclusions from surface exploration that the resource temperature is close to or within 100°C. Drilling indicates that this temperature could be reached with a 1200 – 1500 m deep drill hole.[84]

- **Conceptual Model**

The water is channeled from depth to surface along the fault zone of the Rift Valley escarpments. These are typical low enthalpy systems; no localized heat source is present, and the predicted subsurface temperatures are in the range of 75 – 150°C. In Bugarama the depth to the resource has been estimated to be ≥ 1100 m.[85]

- **Preliminary Assessment**

The Bugarama-Mashyuma geothermal prospect has been classified as an "Inferred Resource" and has a low project weighted score in the analysis.

This geothermal prospect has detailed geological, geochemical, geophysical, soil CO_2 flux surveys and Temperature Gradient Drilling allowing the elaboration of a reasonable geothermal conceptual model. The geochemistry of the waters in Bugarama suggests the presence of a low-temperature geothermal system with a resource temperature between 75 and 150°C.[86] This inferred resource can be utilized as an Organic Rankine Cycle (ORC) Binary plant and/or for direct uses. Overall, this site is one of the most suitable in Rwanda for further study and development, especially for geothermal direct usages such as fish and tea drying and balneology uses.

(2) GISENYI-KILWA GEOTHERMAL PROSPECT

- **Geology**

The Gisenyi area has been divided into 4 geothermal areas: Kilwa, Muti, Gisenyi and Kanzanza. The Kilwa peninsula is a well-defined geographic structure; an island made of compact Precambrian basement (metasediments intruded by granites and associated pegmatites) connected to the mainland by detritic sedimentary deposits (typical simple tombolo structure). The NNW-SSE-striking Kilwa Fault shows a high dip towards the east (i.e., opposite to the lake). In the footwall, the basement rocks – granites, metasediments and pegmatites – are virtually unaltered and a well-expressed fault plane is exposed immediately above the northern spring.[87]

- **Geothermal Manifestations**

The location of the hot springs is intimately associated with the NNW-SSE-striking Kilwa Fault. Two hot-spring sites are found at the lake level on both sides of a narrow and small terrace that connects the peninsula with the eastern shore of Lake Kivu. The water temperatures at the springs vary from the lake temperature up to 73°C.[88]

[84] Mamo et al., 2016.
[85] Gislason, 2016.
[86] Ibid.
[87] "Geophysical Survey Report for Geothermal Consultancy Services Study in support of developing geothermal resources at Rubavu-Kalisimbi," Geothermal development company (GDC) & SARL GEO2D, Report for the Government of Rwanda, 2017.
[88] Ibid.

- **Geochemistry**

Various degrees of mixing between the convective hydrothermal fluids (Na-HCO_3 type) with the Lake Kivu surface waters have been shown. The springs are associated with gaseous emissions with a slight H_2S smell, and iron sulphides are deposited, but altered into iron hydroxide in atmospheric conditions. In the sections with the highest temperatures, the detrital lacustrine sediments are cemented by a matrix rich in sulphides, carbonates and silica. Also, the analysis of the fluids from the springs suggests a magmatic heat source for the system inferred to be located very deep below the lake.[89]

- **Geophysics**

Direct Circuit resistivity and gravity data collection was completed in Kilwa Peninsula in September 2016. The available magnetic data could not be used to identify any fault and was heavily affected by the dense power line network and other anthropic activities. Resistivity models show low resistivity anomalies and are interpreted as faults. The low resistivity associated with the Kilwa fault suggests the effect of hydrothermal fluids that allowed the formation of hydrothermal minerals within the fracture zone. A total of 15 TEM soundings were conducted on either side of the NNW trending Kilwa fault. The resistivity map at 1,000 masl shows high resistivity on either side of the fault to the east and the west, bracketing the low resistivity zone of the fault itself. The low resistivity has a NNW orientation similar to the Kilwa fault.[90]

- **Thermal Gradient Holes/Wells Drilled**

There are no temperature gradient holes or wells drilled in the prospect.

- **Conceptual Model**

Results from multifaceted geoscientific studies reveal the presence of an intermediate-temperature liquid dominated reservoir hosted in basement rocks at the Kilwa Peninsula controlled by the Kilwa fault system. The reservoir temperature is estimated to be 160°C at an approximate depth of 2,000 m. Shallow parts of the reservoir at depths of 800 ± 200 m may host fluids of >100°C. The area is characterized by $NaHCO_3$ hot springs with outlet temperature of 70 ± 2 °C and a flow rate of 2 to 5 l/s acting as the outflow of the system. The heat source of the system is postulated to be deep-seated magmatic dykes that may be associated with the Nyiragongo-Kivu rift tectonic axis. The geometry of the reservoir could not be well defined owing to the limitations of the geoscientific methods deployed and the available data.[91]

- **Preliminary Assessment**

The Kilwa geothermal prospect has been classified as an "Inferred Resource" and has a low project weighted score in the analysis. Kilwa is the most promising site identified out of the four areas in Gisenyi geothermal prospect and Rwanda in general, and the only one for which detailed geological, geochemical, geophysical and soil CO_2 flux surveys allowed a reasonable geothermal conceptual model to be elaborated.[92] The reservoir temperature is estimated to be 160°C at an approximate depth of 2,000 m, suggesting possible development as an ORC Binary plant and/or for direct uses. Overall, this site is one of the most suitable in Rwanda for further study and development, especially for geothermal direct usages such as fish and tea drying and balneology uses.

[89] Ibid.
[90] Ibid.
[91] Ibid.
[92] Ibid.

(3) KARAGO GEOTHERMAL PROSPECT

➢ Geology

Geologically, the Virunga Geothermal Prospect (which includes Karago Geothermal Prospect) is located at the Western branch of the East African Rift System, also called the Albertine Rift, bordered by some of the highest mountains in Africa (the Virunga Mountains, Mitumba Mountains, and Ruwenzori Range) and containing the Rift Valley lakes (e.g. Lake Tanganyika - 1,470 m). Lake Karago is a smaller lake in this system.[93]

The Karago area is situated in the Proterozoic basement (granite), and there is no recent volcanism in or around the area. It is supposed that thermal springs in the area are associated with the deep circulation of natural waters across faults, and the high temperature results from the relatively high geothermal gradient, or the conductive heat of the magmatic materials situated in a deeper part of the crust, or the conductive heat of intrusive rocks.[94]

➢ Geothermal Manifestations

The spring at Lake Karago (64,1 °C) exhibits one of the highest temperatures in the region. Fairly small outflow rates of up to 4 l/s were estimated in the sampled springs. Some springs showed relatively weak gas emanations.[95]

➢ Geochemistry

Extensive studies were conducted by BRGM in the early 1980s at hydrothermal springs in the western and southern parts of the country. A total of 845 soil gas efflux and temperature measurements, 728 soil gas radon measurements, and 817 soil gas samples were performed during the gas survey.

The CO_2 efflux values ranged from below detection limit (< 20 g/m2/d) to a maximum value of 3.244 g/m2/d, measured at the Karago hot spring. Diffuse H2S efflux was also measured at all points. However, only two places exhibited efflux values above the detection limit of the instrument (0,01 mg/m2/d). These values (0,68 mg/m2/d and 0,05 mg/m2/d) were measured around the hot springs at Lake Karago.[96]

Karago hot spring is of neutral HCO_3 type and the components of its major cations are Na+K. Chloride (Cl) concentration is relatively high.[97] The temperature of the Karago hot spring water is rather high (64.1°C-73°C) and the pH is neutral (7.2), but the total flow is low. According to the Institute of Earth Science and Engineering (IESE), there are warm springs and CO_2 discharges from a small swampy area on the south shore of Lake Karago. The total mass flow is low, little more than 1 liter per second.[98]

There are two hot springs in the Karago area, Karago and Mbonyebyombi hot springs. Considering the geology, geological structures, and distribution of thermal manifestations in the area, it seems that the flow of hot fluid is strongly controlled by permeable zones related to faults and fractures. In general, faults play an important role in ensuring vertical permeability in a geothermal system.

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[93] Jolie, E., "Geothermal Exploration in the Virunga Prospect, Northern Rwanda", Proceedings World Geothermal Congress, 2010.
[94] JICA, 2016.
[95] Jolie, 2010.
[96] Ibid.
[97] JICA, 2016.
[98] Ibid.

In the Karago area, NW-SE trending topographic lineaments are well detected, which implies the presence of faults. These inferred faults are considered to be permeable zones related to the path of fluid flows in the Karago area. The Na-K-Ca geothermometers estimated underground temperatures between 159°C and 204°C for Karago high-temperature hot springs.[99]

- **Geophysics**

No detailed or regional geophysics survey (magnetics, gravity, or similar) had previously been implemented in the prospect. In 2009-11, KenGen implemented a regional TEM study near the prospect, where a few MT stations gave some idea about the structures. MT resistivity survey showed that the granitic basement rocks in the Gisenyi-Ruhengeri area generally have very high resistivity. Isolated lower grounds in the study area contain hydrated sediments (e.g. silt, sand) and exhibit low resistivity values near the surface. The Ndorwa hot spring near Lake Karago and the Gisenyi hot springs at the shores of Lake Kivu, where hydrothermal fluids find their way to the surface through fractures, display moderately low resistivity at the surface. It is assumed that this is caused by alteration of the rocks along the fractures.[100] Low resistivity rocks (< 20 ohm m) occur below 7 km depth beneath the Lake Karago area.[101]

The hot spring area at Karago shows relatively low resistivity at depth compared with the high resistivity zone widely distributed in the area north of Karago. However, only a few MT stations are located in and around the Karago area, and no MT data was collected in the east, west or south part of the Karago area; thus, the subsurface resistivity structure around the Karago area could not be defined properly.[102] A relatively low resistivity zone is detected below the Karago area at greater depth. There is a possibility that a relatively high-temperature zone is present at depth in the Karago area.[103]

- **Thermal Gradient Holes/Wells Drilled**

There are no thermal gradient holes or wells drilled in the area.

- **Conceptual Model**

The geophysical survey results show that the manifestations are an expression of a separate system, from the heat source associated with Karisimbi, Visoke or Sabyinyo volcanoes. The heat discharged is therefore a result of descending ground water being heated by the thermal gradient before returning to the surface along faults and fractures. The depth of water penetration may have been 2500m, assuming a thermal gradient of about 30°/km.[104]

- **Preliminary Assessment**

The Karago geothermal prospect has been classified as an "Inferred Resource" and has a low project weighted score in the analysis.

This prospect has preliminary geological, geochemical, and geophysical studies which needs to be revisited in order to elaborate a sufficient geothermal conceptual model. But JICA has implemented a Monte Carlo study using all available and related data, which resulted in a Resource Potential at 80% Confidence Level

[99] Ibid.
[100] Jolie, 2010.
[101] Shalev, E., Browne, P., Wameyo, P., Hochstein, M, Palmer,J. and Fenton, R.,"Geoscientific Surveys of the Rwandan Kalisimbi, Gisenyi and Kinigi Geothermal Prospects", FINAL REPORT 18.2012.02, 2012.
[102] JICA, 2016.
[103] Ibid.
[104] Shalev et al., 2012.

of 2.5 MW and a 4.9 MW for Resource Potential at 50% Confidence Level. The hot water at 73ºC is currently welling up, but the establishment of facilities like Spa and hot pools could be difficult because the acreage is limited. In a case where steam around 190ºC is obtained from the subsurface, there is potential for geothermal use for drying tea leaf at a tea processing factory.[105] In sum, the Karago geothermal prospect shows a promising backdrop for low- to moderate-temperature resources which can be utilized for power (ORC) or other direct uses.

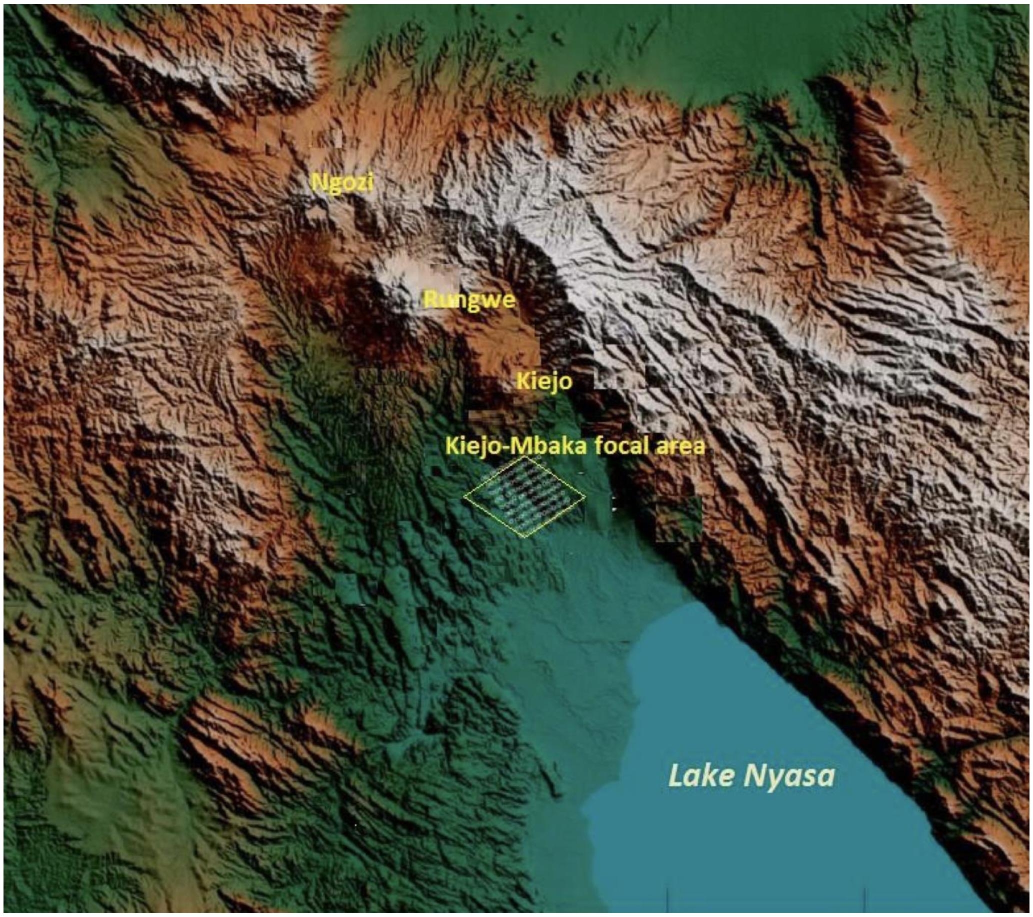
[105] JICA, 2016.

2.5 TANZANIA

2.5.1 Geothermal Sector Overview

Tanzania is transected by the East African Rift System (EARS) which has been found to create geothermal resources suitable for power generation and direct use. The eastern branch of EARS transects the country from the north near Lake Natron to the south, where it meets the western branch of EARS at Mbeya. Some reports, e.g. Kajugus et al. (2018),[106] suggest that Tanzania has a geothermal potential of more than 5,000 MW from several sites in the country. Because of this recognized potential, the Government of Tanzania, in its 2016 Power Sector Master Plan update, set a target of 200MW contributed to the national grid by geothermal energy by 2025. In order to reach the target, the Government of Tanzania established the Tanzania Geothermal Development Company (TGDC) to fast track exploration and development of geothermal resources in the country. TGDC developed an elaborate plan to expedite the exploration of geothermal prospects, starting with the Ngozi geothermal area, which is expected to be a high-temperature resource. However, the timeline may not be achieved, since exploratory drilling is yet to be undertaken in any of the prospects.

Figure 17: Map of Kiejo-Mbaka Volcano



Source: Kajugus et al., 2018

[106] Kajugus, S.I., Kabaka, K.T. and Mnjokava, T. 2018. Geothermal Development in Tanzania - a Country Update. Proceedings, 7th African Rift Geothermal Conference Kigali, Rwanda 31st October – 2nd November 2018.

2.5.2 Summary of Available Data and Gaps in Data

The Tanzania Geothermal Development Company (TGDC) has indicated that they would only benefit from analysis of the Kiejo-Mbaka geothermal field. Thus, the data that has been shared includes only this field's available information, and we reduced the scope of the analysis for this country to this field alone. Several studies have been implemented in the Kiejo-Mbaka field; the most advanced study is a conceptual model based on geoscientific data. Therefore, further in-situ studies are needed: slim holes and temperature gradient holes have been planned for 2020, and results from these wells will guide resource confirmation and will allow further assessment of the area's geothermal potential.

Table 9: Summary of Existing Data Available for Tanzania

Name of Document/Report	Source	Date (publication)	Name of geothermal site(s)
Survey of the Opportunities for Direct-Use Applications at the Kiejo-Mbaka Geothermal Prospect	TGDC	2019	Kiejo-Mbaka
Geothermal Development in Tanzania - a Country Update	TGDC	2018	Country-wide
Surface Exploration and Training in Luhoi and Kiejo-Mbaka Geothermal Areas, Tanzania	TGDC	2017	Luhoi and Kiejo-Mbaka
A Guide for the Development of Geothermal Direct-Use Projects in Tanzania	DFID – East Africa Geothermal Facility	2017	Country-wide
Data Collection Survey on Geothermal Development in East Africa: Tanzania Report	JICA	2014	Country-wide

2.5.3 Summary of Findings

A summary of findings of the Kiejo-Mbaka site is presented in **Table 10** and **Figure 18**.

Table 10: Classification and Weighted Scoring for Kiejo-Mbaka Geothermal Site in Tanzania

No.	Geothermal Resource	Classification	Classification Score	Project Weighted Score
1	Kiejo-Mbaka	Indicated Resource	20	22

Source: GreenMax Capital Advisors analysis

(1) KIEJO-MBAKA SITE

The high potential areas in Tanzania are the following: (a) the Lake Natron region near the Kenyan border in the north, (b) the Mbeya region between Lake Rukwa and Lake Nyasa in the southwest, (c) the Rufiji basin in the east, and (d) the central Tanzania region. In northern Tanzania, geothermal activity occurs mainly along the southern extension of the Kenya rift into the L. Eyasi, Ngorongoro, L. Natron, Ol'Doinyo Lengai and Arusha areas. The prospects in the Mbeya region are associated with the Rungwe volcanic complex and include the Ngozi, Songwe, and Kiejo-Mbaka geothermal areas. In the Rufiji basin in eastern Tanzania occur the Luhoi, Kisaki and Utete sites. Other geothermal areas are located in central Tanzania and include the Singida, Kondoa, Dodoma and Shinyanga areas. Most of these geothermal areas are low- to medium-temperature resources, with Kiejo-Mbaka being one of the most important.

Figure 18: Map of Kiejo-Mbaka Geothermal Site in Tanzania

Source: ARGeo Africa Geothermal Inventory Database; GreenMax Capital Advisors analysis

- **Geology**

Kiejo-Mbaka geothermal area comprises the area of geothermal activity covered by the volcanism of the Kiejo Mountains and the manifestations of the Mbaka fault. Kiejo is an active volcanic field with the most recent activity dated to about 1800 AD. The volcanic products are strongly undersaturated, with nephelinitic rocks, basalts, basanites, picrites, and their pyroclastic products being dominant. Studies reveal that the magmas were produced by low degrees of partial melt from deep sources in the mantle and erupted on the surface with little contamination or mixing. From the above observations, Kiejo volcano itself is not expected to have any significant shallow magma bodies that could be heat sources for a large geothermal system.

The Mbaka fault lies to the south of Kiejo volcanic field and is defined by a large fault scarp that down faulted the Precambrian Ubendian gneiss. At this site, the Ubendian gneiss is unconformably overlain by the Karoo sediments (mainly Permian) which are exposed at the western side of the Karonga basin. Karoo conglomerates that are unconformably overlain by the Red sandstones and siltstones are exposed in some sites. The Sandstone group is unconformably overlain by a basal unit that comprises thin, muddy sandstones of a volcano-sedimentary sequence. On the footwall of Mbaka fault, the young volcanic eruption products of Rungwe volcanic complex directly overly the Precambrian basement formations. Several volcanic cones occur on the hanging wall of the Mbaka fault, and these have compositions similar to those of the Kiejo proper.

Several fault systems have been recognized, among which the most important ones are NW-SE and N-S. The Mbaka fault, which controls the emergence of hot water and delimits the Mbaka ridge to the west, belongs to the NW-SE system and is associated with a series of parallel structures extending in the plain. The Kisyelo fault, which delimits the Mbaka ridge to the east, trends N-S to NNW-SSE.

- **Geothermal Manifestations**

The springs along the Mbaka fault discharge about 20 to 40 kg/s of hot (up to 70ºC) bicarbonate waters with significant artesian flow (spouting springs) in some locations. Travertine deposits are widespread, especially along creeks which drain the area. Fumaroles, steaming grounds, and hot grounds occur on the upthrow side of the Mbaka fault.

- **Geochemistry**

Fluid geochemistry indicates that sampled fluids of the Mbaka hot springs are classified as "peripheral waters" and bicarbonate-rich according to Kraml et al. (2012).[107] This is further confirmed by Na-K-Mg diagrams which show all data plotting in the immature or partly equilibrated field. The springs contain 151 mg/kg of SiO_2, pointing to a geothermometric temperature $T_{(CH)}$ of 140ºC.[108] Later studies by Kraml et al. (2012) estimated the reservoir temperature of Mbaka to be more than 160°C based on mixing of an equilibrated hydrothermal fluid with (near-) surface waters.

- **Geophysics**

Geophysical techniques employed for the evaluation of the geothermal system at Mbaka were gravity and resistivity (MT/TEM). Results of ELC (2017)[109] revealed the existence of a block characterized by a pronounced positive Bouguer anomaly which follows the extension of the Mbaka ridge, corresponding to outcropping basement rocks. The downthrow side shows a low gravity anomaly indicating thick sedimentary infill. Results of joint inversion of MT and TEM revealed a similar pattern to gravity, with the Mbaka ridge showing high resistivity and the basins adjacent to it showing good conductivity. West of Mbaka fault, resistivity analysis shows a very conductive layer (~2 Ohm m, thickness ~610 m) centered at a depth of about 510 m, and a very conductive layer (1 Ohm m, ~1,500 m thick) centered at a depth of about 1,400 m. This is the area where a TGH drill encountered high temperatures.[110] A resistive layer (~55 Ohm m) occurs at a depth of about 2,300 m.[111]

[107] Kraml, M. Kreuter, H., Robertson. G. and Mbaka exploration team members, 2012. Small-Scale Rural Electrification and Direct Use of Low-Temperature Geothermal Resources at Mbaka Fault in SW Tanzania. ARGeo-C4, Nairobi, Kenya.
[108] ELC, 2017. "Surface exploration and training in Luhoi and Kiejo-Mbaka geothermal areas, Tanzania." Final Report (2017).
[109] Ibid.
[110] TGDC, 2017. Geothermal Resources Project Proposal Document for Tanzania. Prepared by Norton Rose Fulbright, Carbon Counts, and SEPCO under contract No: PA/131/2016-17/C/05.
[111] ELC, 2017.

- **Monitoring Wells**

There are currently no monitoring wells drilled in the area, but a prospector drilled a shallow well terminating at 70m depth and offset about 500m from Mbaka fault trace encountered high temperatures. Drilling was stopped and the well abandoned due to the hot water discharge.

- **Conceptual Model**

The model for the Mbaka geothermal system is explained by a fault-controlled model. It has been observed that all manifestations occur along the toe of the NW-SE Mbaka fault with large deposits of travertine being common. Kraml et al. (2012) noted that most of the hot springs occur at the intersections of NW-SE (Mbaka fault) and NNE-SSW (Usangu rift trend). The fluids are rich in HCO_3 which could be due to the association of the geothermal system with deep-seated faults that channel degassing CO_2 from the mantle to the surface. Such high CO_2 levels are observed at Songwe which lies a few kilometers NW of the Mbaka geothermal area. The heat source for the geothermal system is most likely associated with heat sweep at the contact between the basement and the overlying volcano-sediments in the hanging wall block at Mbaka.[112] Some contributions from dike intrusions along the fault line are also highly plausible. Another hypothesis is that the fluids are an outflow from a concealed geothermal reservoir in the north. The geothermal system is postulated to extend more than 500 m to the west away from the fault trace and have a NW-SE extent of more than 1 km, and maximum reservoir thickness of 2.3 km. Hochstein et al., 2000 estimated that between 3.5 and 7 MWt is discharged by the springs. The fluids are non-equilibrated, indicating that the Kilambo springs at the Mbaka fault are likely an outflow of thermal water derived from a concealed reservoir further upstream.[113]

- **Preliminary Assessment**

The Kiejo-Mbaka geothermal field is one of Tanzania's five prioritized geothermal prospects – Ngozi, Songwe, Kiejo Mbaka, Luhoi, and Natron. The analysis found that the site is an "Indicated Resource" with a relatively low project weighted score.

There is a high chance that a medium-temperature resource will be discovered in Mbaka with a predicted resource temperature of about 150º. Such temperatures are adequate for binary power generation using ORC technology, which can be used for temperatures greater than 130º. The area along the Mbaka fault that could contain geothermal reservoirs is large, and it is anticipated that several MW can be produced from the field. Mbaka is an agriculturally rich area, which presents an opportunity for the development of direct use projects. The shallow medium-temperature resource can be developed for many applications, including drying of cashew nuts, drying of grain, aquaculture (fish), greenhouse heating, milk and fruit pasteurization, cooling and refrigeration, ethanol and biodiesel manufacture, fish drying, and vegetable drying/dehydration, among others.[114]

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[112] McNitt, J.R., "A New Model for Geothermal Exploration of Non-Volcanic Systems in Extended Terrains," Arizona Geological Survey, 2002; and Hochstein, M.P., Temu, E.P., Moshy, C.M.A., "Geothermal Resources of Tanzania: Proceedings World Geothermal Congress 2000, Kyushu - Tohoku, Japan, 2000.

[113] Ibid.

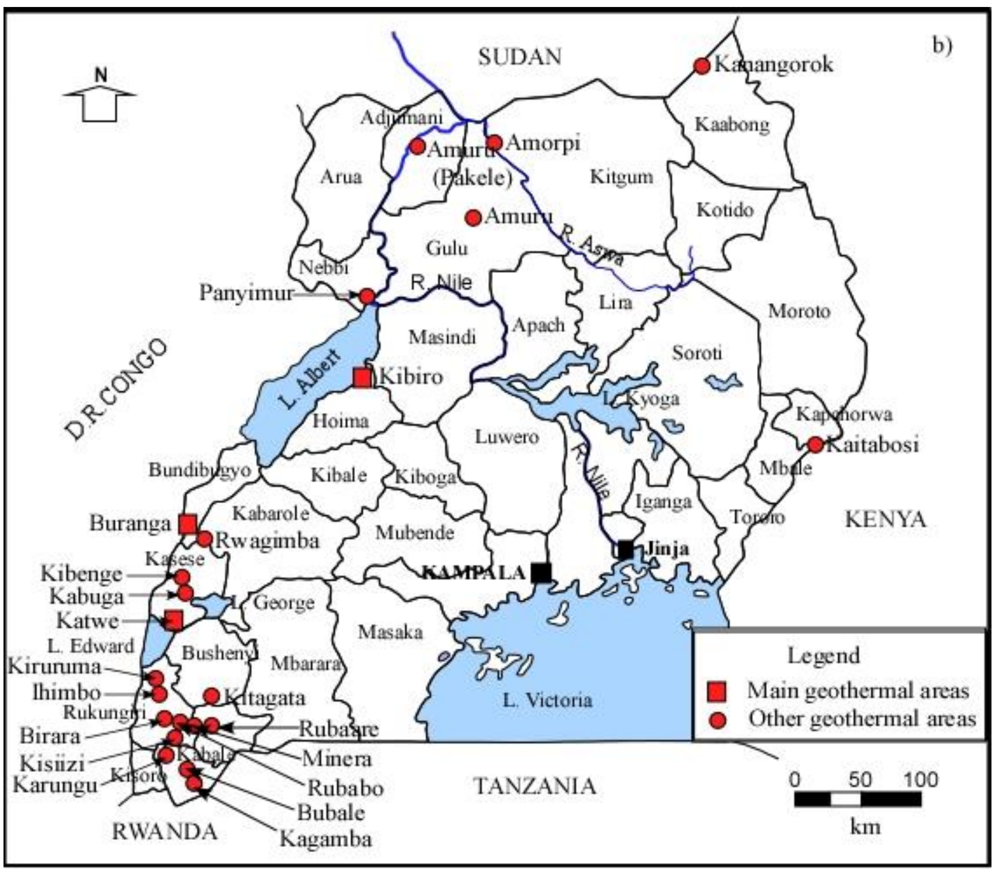
[114] Lund, J., 2017, "A guide for the development of geothermal direct-use projects in Tanzania," East Africa Geothermal Energy Facility (EAGER) report prepared for Tanzania Geothermal Development Company.

2.6 UGANDA

2.6.1 Geothermal Sector Overview

Uganda has an estimated geothermal potential of 450 MW for power generation. This estimate was further increased to 1,500 MW under the Uganda Vision 2040 Projects.[115] More than 40 geothermal sites have been studied to identify project areas and prioritize certain prospects for further development. The country's three main geothermal sites located in or near the Western Rift Valley of Uganda include Panyimur, Buranga and Kibiro. These three areas have been prioritized due to their volcanic and tectonic features, which are indicators of powerful heat sources and permeability. Five other sites have been selected for surface exploration: Panyimur, Kitagata, Ihimbo, Kanangorok and Rubaare.

Figure 19: Map of Geothermal Sites in Uganda



Source: Geothermal Resources Department, 2019

2.6.2 Summary of Available Data and Gaps in Data

A summary of the data that was available for Uganda is presented in **Table 11**.

115 Zakkour, P. and Cook, G., "Formulation of Geothermal Energy Policy, Legal and Regulatory Framework in Uganda," Prepared by Carbon Counts Company (UK) Ltd. for Climate Technology Centre and Network, 2016.

Table 11: Summary of Existing Data Available for Uganda

Name of Document/Report	Source	Date (publication)	Name of geothermal site(s)
Status of Geothermal Energy Resources Development in Uganda	Ministry of Energy and Mineral Development	2019	Country-wide
Market Opportunities for the Direct Use of Low Temperature Geothermal Heat in Uganda	Institute of Water and Sciences, Pan African University	2018	Country-wide
Review of Ugandan Geothermal Prospects	DFID East Africa Geothermal Facility	2018	Country-wide
Panyimur and Kibiro: Indicative Pre-feasibility Study	DFID East Africa Geothermal Facility	2018	Panyimur and Kibiro
Status of Geothermal Energy Exploration at Katwe Geothermal Prospect, Western Uganda	Ministry of Energy and Mineral Development	2018	Katwe Geothermal Prospect
Geothermal Exploration in Uganda – Status Report	Ministry of Energy and Mineral Development	2017	Country-wide
Status of Geothermal Energy Exploration at Buranga Prospect Western Uganda	Ministry of Energy and Mineral Development	2016	Buranga Prospect
Formulation of Geothermal Energy Policy, Legal and Regulatory Framework in Uganda	CTCN	2016	Country-wide
Resource Study for the Direct Use of Low Temperature Geothermal Heat in Uganda	Institute of Water and Sciences, Pan African University	2016	Country-wide
Technical Review of Geothermal Potential of Kibiro Geothermal Prospect, Uganda	Middle Earth Geoscience Ltd.	2016	Kibiro Prospect
The Three Geothermal Prospects of Uganda; Kibiro, Katwe and Buranga – Geology and Geothermal Surface Manifestations	Ministry of Energy and Mineral Development	2015	Kibiro, Katwe and Buranga
The Geology and Potential of Kibiro Geothermal Field in Albertine Graben, Western Uganda	Geological Survey of Uganda	2015	Kibiro Prospect
Data Collection Survey on Geothermal Development in East Africa: Uganda Report	JICA	2014	Country-wide

Most of the country's resources have had a wide range of studies undertaken, including geology, geochemistry, geothermal manifestations, geophysics including up to MT/TEM studies, and some preliminary conceptual models. Additional gradient wells, Thermal Gradient Holes and/or slim hole wells are needed where temperature, pressure and flow measurements can be taken. Additionally, regional and local scale geophysics studies with geochemistry data can be utilized to conduct conceptual models and thus enable deep conventional well targeting.

2.6.3 Summary of Findings and Geothermal Site Selection

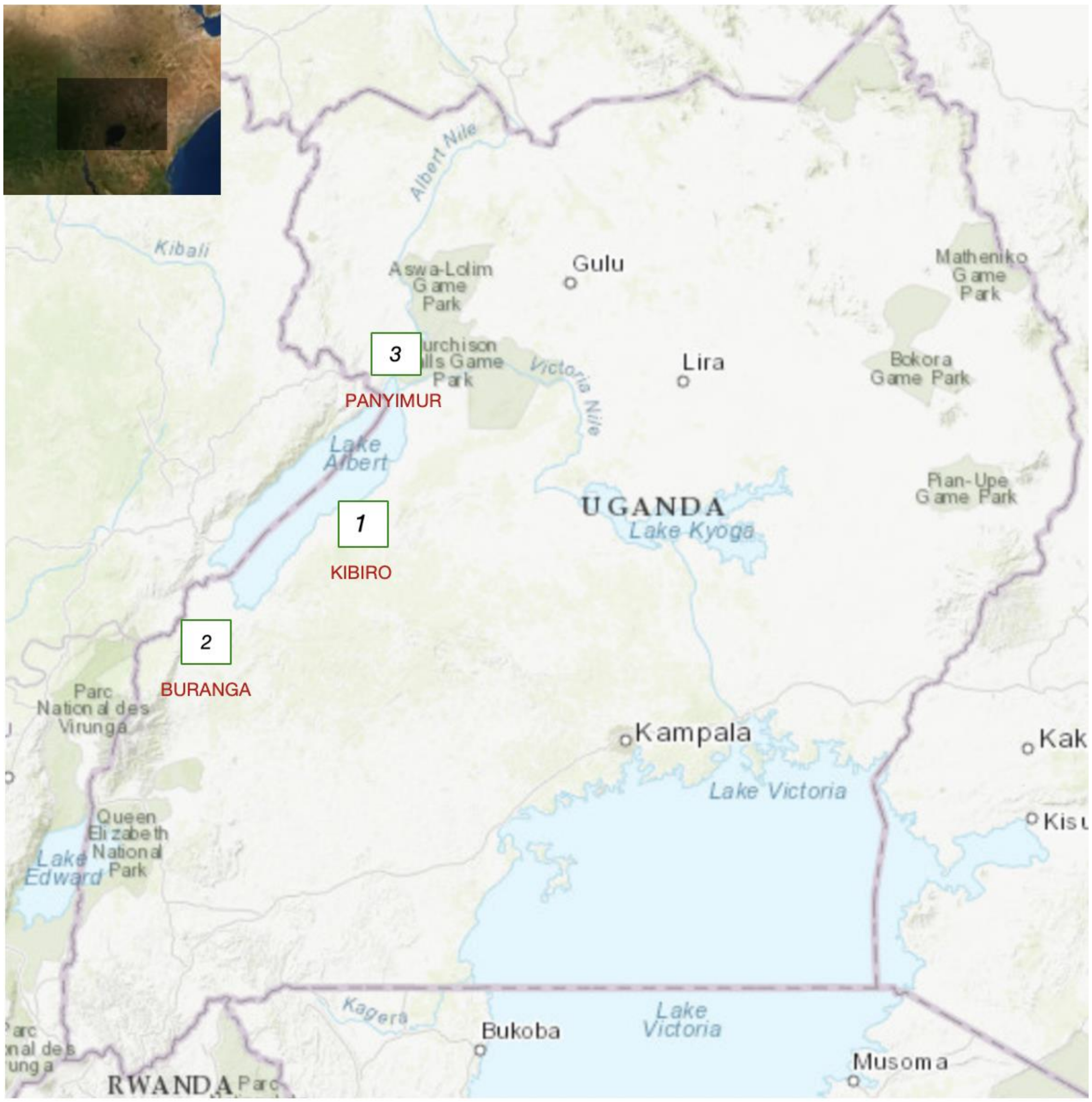
The top three sites identified for Uganda are presented in **Table 12** and **Figure 20**.

Table 12: Geothermal Site Selection and Weighted Scoring for Uganda

No.	Geothermal Resource	Classification	Classification Score	Project Weighted Score
1	Kibiro	Indicated Resource	11	17
2	Buranga	Indicated Resource	10	15
3	Panyimur	Inferred Resource	10	15

Source: GreenMax Capital Advisors analysis

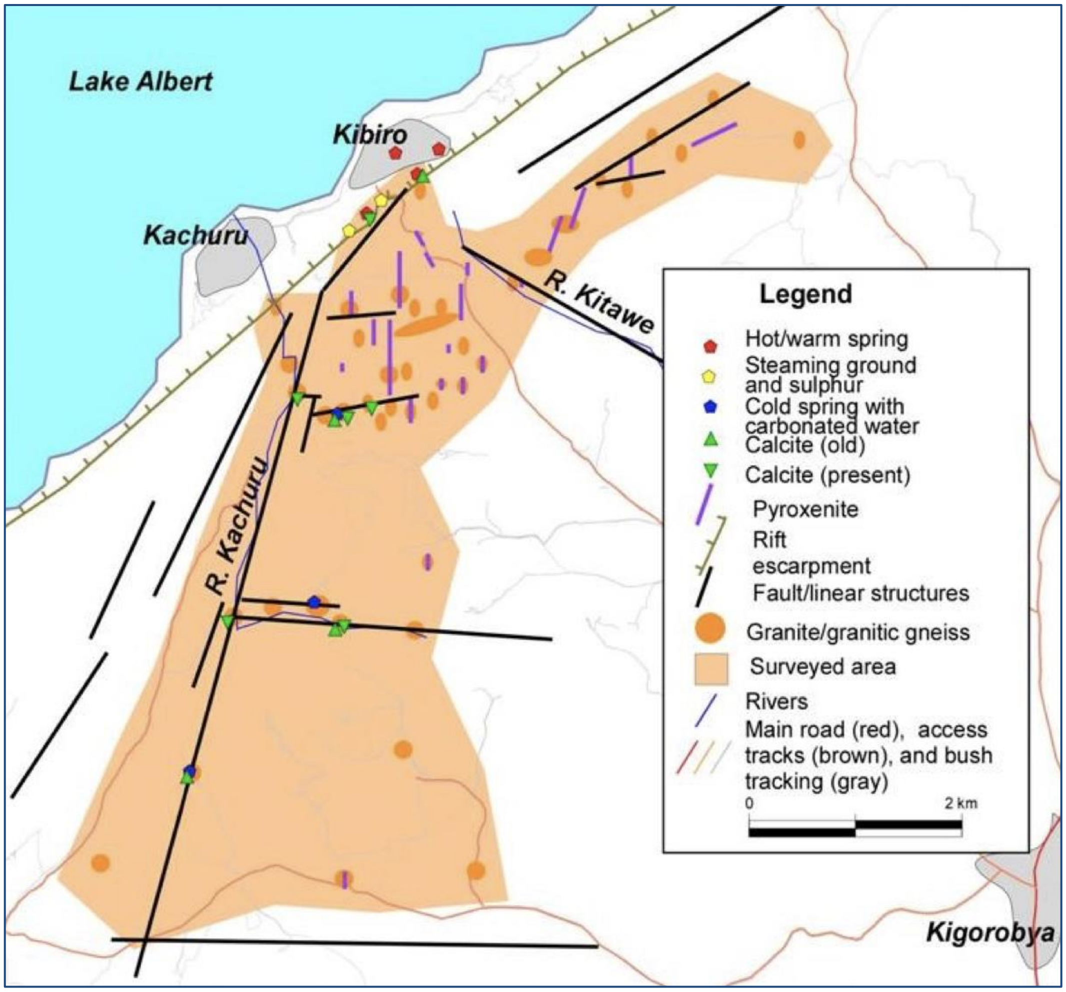
Figure 20: Map of Selected Geothermal Sites in Uganda



Source: ARGeo Africa Geothermal Inventory Database; GreenMax Capital Advisors analysis

(1) KIBIRO GEOTHERMAL PROSPECT

Figure 21: Map of Kibiro Geothermal Prospect



Source: Ugandan Ministry of Energy and Mineral Development

- **Geology**

The Kibiro geothermal prospect is located at the foot of the Eastern escarpment of Albertine Rift bound by Lake Albert on the west. The Toro-Bunyoro fault is the main NE-SW rift fault that bounds Lake Albert on the east and is composed of Precambrian crystalline basement characterized by granites and granitic gneisses while to the west are the thick rift sediments of the Lake Albert graben estimated at 5.5 km in thickness.[116]

[116] Abeinomugisha, D., "Development of a petroleum system in a young rift basin prior to continental break up: The Albertine graben, of the East African Eift System, AAPG, Search and Discovery Article #10284," (2010): http://www.searchanddiscovery.com/documents/2010/10284abeinomugisha/; and Alexander, K., Cumming, W.B., and Marini, L., "Geothermal Resource Assessment Report, Kibiro geothermal prospect, Uganda," (2016).

- **Geothermal Manifestations**

Surface thermal manifestations in the Kibiro geothermal prospect are mainly concentrated at Kibiro site at the shores of Lake Albert. There are three sites of manifestations. Mukabiga is the main discharge area located in a ravine at the base of the fault escarpment (T = 87 - 81°C). A second group of hot or warm springs is found downstream in an area of salt gardens called Mwibanda (T up to 72°C). Directly north of Mukabiga is Muntere, which forms the largest salt flat (T=40 - 45°C). The manifestations mainly comprise of hot and warm springs and minor Sulphur encrustations at some sites. The fumarolic activity is distributed widely at the foot and slopes of the escarpment while the hot springs occur at the intersection of the main escarpment fault and the cross-cutting oblique faults. The total flow from the hot springs has been estimated at 6.5kg/s at an average discharge temperature of 68ºC (max 86.4°C) giving estimated output of 0.1 MW.[117]

- **Geochemistry**

The fluids of Kibiro geothermal prospect are characterized by a neutral pH, and salinity of up to 5,000 mg/kg TDS. Fluid chemistry data indicate that the composition of the fluid is dominated by NaCl which accounts for over 90% of the total TDS. Gas discharge is dominated by methane. Results from different geothermometers for hot water samples from Kibiro fell into two groups, one showing a temperature of about 150°C and another 200-220°C.[118] Gislason et al., 2004[119] provided alternative geothermometric calculations based on K, Na, Mg with TK-Mg indicating 140-160ºC while that indicated by T K-Na is 220-240ºC. Silica indicated at a temperature of 136±6°C while K-Mg gave a temperature of 148±3°C which reflects the reservoir temperature at depths of about 2 km under the hot springs area.[120]

- **Geophysics**

The surface exploration studies conducted in Kibiro comprised of gravity, magnetics, VES Schlumberger resistivity, seismic and MT/TEM methods.[121] Resistivity studies revealed a conductor aligned along the foot of the escarpment which suggested a fault controlled reservoir.[122]

- **Thermal Gradient Holes**

The drilling of six thermal gradient wells up to 300 m depth in the up thrown basement, did not show any thermal anomaly nor did they show presence of hydrothermal alteration. Additional drilling is underway in the down thrown block and high temperature was encountered in the first well.

- **Conceptual Model**

The geothermal system at Kibiro is a fault controlled reservoir with the main up-flow occurring at the intersection of the fault systems (NE-SW and MW-SE). The reservoir is thought to occur within the arenaceous sediments of Lake Albert rift basin. It is estimated that the reservoir could be at temperature of

[117] Alexander et al., 2016.
[118] Ármannsson, H., "Geochemical studies on three geothermal areas in West and Southwest, Uganda Final report," Geothermal Exploration UGA/92/003, UNDESD, GSMD, Uganda, 1994.
[119] Gislason, G., Árnason, K., Eysteinsson, H., "The Kibiro geothermal prospect; A report on a geophysical and geological survey prepared for Icelandic International Development Agency and Ministry of Energy and Mineral Development, Uganda," 2004.
[120] Alexander et al., 2016.
[121] Gislason et al., 2004.
[122] Alexander et al., 2016.

about 150ºC at about 2 km depth.[123] The fluid chemistry is expected to have moderate to high salinity. The system in Kibiro can be compared to that in the Basin and Range province in USA.[124]

- **Preliminary Assessment**

The Kibiro geothermal prospect has been classified as an "Indicated Resource" and has a low project weighted score in the analysis.

The data suggests a promising prospect as it manifests geothermal geology analogy, existing surface manifestations, a high geothermometer expectation reaching up to 200ºC, moderate salinity and completed full suite geophysics studies suggesting a structurally controlled resource. On the other hand, the prospect lacks data from the six thermal gradient wells drilled and details in fluid flow.

A pre-feasibility study of the site completed by EAGER in 2018 found that Kibiro had both technical indications as well as local demand for direct use geothermal applications. Overall, this site is suitable for geothermal direct use and is recommended for further study.

(2) BURANGA GEOTHERMAL PROSPECT

- **Geology**

Buranga is located at the foot of the Rwenzori massif near the base of Bwamba escarpment that strikes N45ºE and dips N60-65ºE. Buranga area has no evidence of volcanism but is highly tectonically active. The hot springs emerge through sediments of the Semiliki plains, which consist of Kaiso beds and peneplain gravels of variable sands, gravels and boulders. The sediments are estimated to have a thickness of about 1.5 km. The main rift fault escarpment forming the northern half of the Rwenzori massif, which is composed of migmatites, gneisses and amphibolites.[125]

- **Geothermal Manifestations**

The hot springs lie on a fracture/fault line parallel to main rift fault. The springs are situated in a swamp a few hundred meters westerly of the Bwamba fault, which forms the western flank of the Rwenzori and the eastern scarp of the rift, respectively. The Buranga hot springs consist of 37 springs localized in three areas namely Mumbuga, Nyansimbe and Kagoro. Nyansimbe is a large water pool while Mumbuga is erupting hot springs. The overall flow rate from the springs is 30 l/s and temperatures up to 98.4°C, which is close to local boiling point.[126] In the whole of the western branch of the East African Rift System, Buranga has the most impressive and largest surface thermal manifestations.

- **Geochemistry**

Geothermometry using fluid and isotope techniques reveal medium temperature system at T=120-150ºC for Na/K.[127] A subsurface temperature of 200°C is predicted by isotopic geothermometers (JICA, 2014).

[123] Ibid.

[124] Faulds, J.E. and Hinz, N.H., "Favorable tectonic and structural settings of geothermal systems in the Great Basin Region, Western USA: Proxies for discovering blind geothermal systems. Proceedings of the World Geothermal Congress 2015, Melbourne, Australia," 2015.

[125] Natukunda, J.F. and Bahati, G., "Status of Geothermal Energy Exploration at Buranga Proapect, Western Uganda. Proceedings, 6th African Rift Geothermal Conference," Addis Ababa, Ethiopia, (2 - 4 November 2016).

[126] Ochmann, N., Lindenfeld, M., Barbirye, P. and Stadtler, C., "Microearthquake survey at the Buranga geothermal prospect, Western Uganda," Proceedings of the Thirty-Second Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, United States, 2007.

[127] "Status of Geothermal Energy Resources Development in Uganda," Ministry of Energy and Mineral Development, 2019.

The gas composition is dominated by CO_2 and has no H_2 which suggests that the subsurface temperature is less than 200°C.[128] The fluids are neutral with a pH of 7-8 and very high salinity of 14,000-17,000 mg/kg TDS with low SiO_2 and H_2S but high CO_2 (total), SO_4, Cl, and Na.

- **Geophysics**

The geophysical studies undertaken in the area include gravity, MT/TEM and seismic. The TEM survey was aimed at mapping shallow structures and for static shift correction on the MT soundings made on the same site, and the MT survey was used to map deeper resistivity structures of the area. A contact zone between the resistive Rwenzori massif rocks and the conductive low land area is clearly delineated and forms the main reservoir for the geothermal system. Seismic similarly mapped the fault structure which is coincident with the sites of hot spring discharge. Seismic further revealed deep hypocenters.[129] Results of geophysics therefore indicates that the geothermal system is fault controlled and occurs along the main structural features at the boundary between the sediments and faulted Precambrian Ruwenzori formation.

- **Thermal Gradient Hole**

Geothermal investigation at Buranga begun way back in 1954 when four shallow wells were drilled in the prospect (max. 349 m). Exploration results were not good and so the project was abandoned until new interest in the project began in 1990s.[130] Data is not available to indicate the temperatures encountered.

- **Conceptual Model**

The resource at Buranga is a fault controlled system with the heat source postulated to be deep fluid circulation along the fault plane. Isotope hydrology results indicate the source of the geothermal fluids at Buranga to be from high ground in the Rwenzori Mountains; subsurface temperatures of 200°C have been predicted; source of heat is from deep circulation and reservoir rock types are granitic gneisses. The faulted and fractured basement of the Rwenzori provides adequate permeability necessary for recharge and thermal fluid upflow at Buranga.[131] Some recharge is anticipated to come from the basin adjacent to the site.

- **Preliminary Assessment**

The Buranga geothermal prospect has been classified as an "Indicated Resource" and has a low project weighted score in the analysis.

The data suggests a promising prospect as it manifests geothermal geology analogy, existing surface manifestations, a high isotopic geothermometer expectation reaching up to 210℃, and completed geophysics studies suggesting a fault-controlled resource. On the other hand, the prospect lacks data from the four thermal gradient holes drilled as well as geoscientific data, and the resource has high salinity. An assessment by Natukunda et al. in 2018[132] found the potential for marketability of geothermal energy in eight of the most promising geothermal sites in Uganda, which included Buranga. On the whole, having initial surveys completed and showing promise, the site is among of the most suitable that can be further studied and developed for low-to-moderate temperature geothermal direct uses.

[128] Ármannsson, 1994.
[129] Ochmann et al., 2007.
[130] Kato, V., "Pre-Drilling Geothermal Investigation Surveys in Uganda. Proceedings, 7th African Rift Geothermal Conference. Kigali, Rwanda," (31 October – 2 November 2018).
[131] Natukunda and Bahati, 2016.
[132] Ibid.

(3) PANYIMUR GEOTHERMAL PROJECT

- **Geology**

The Prospect is characterized by a step-faulted topography comprising of high-rising ridges with intervening deep valleys. The area is dominated by two major NNE-striking faults with normal, down-to-east displacement making this setting a step-over between pure normal faults in contrast to a pull-apart between oblique- or strike-slip faults. The rock types in the area are Precambrian metamorphics.

- **Geothermal manifestations**

Hot springs occur mainly along the fault traces with outflow temperature of 36-61.4^{o}C. Inactive travertine spring mounds are associated with both the Upper and Lower Faults. Active travertine mounds are only building along the Upper Fault.

- **Geochemistry**

The geothermal fluids are slightly above neutral with a pH of 7-9 and low salinity of 300 – 900 mg/kg total dissolved solids. Presence of some H_2S has been recorded but the origin of the gas is unknown since there are no recent volcanoes in the vicinity. In the triangular diagram of major anions, the Panyimur hot springs plot close to the Cl vertex. Geothermometry estimates reservoir temperatures of more than 100-140^{o}C.

- **Geophysics**

Geophysics studies carried out in the area included gravity, magnetics, and MT/TEM. The gravity and magnetic methods delineated the major NE-SW trending fault. The fault was also seen in MT/TEM data as the major control on resistivity distribution with up-thrown side recorded high resistivity.

- **Conceptual model**

The conceptual model developed for Panyimur suggests up-flow at 125^{o}C along the fault line which then outflows into the shallow sand layers. The geothermal system is therefore postulated to be a fault controlled system.

- **Preliminary Assessment**

The Panyimur geothermal prospect has been classified as an “Inferred Resource” and has a low project weighted score in the analysis.

Several studies have been carried out at this site including, geology, geochemistry and geophysics, all inferring that there is a viable geothermal resource. The geothermometers indicate a reservoir temperature up to 140℃ and a fault-controlled environment. A pre-feasibility study of the site completed by EAGER in 2018 found that Panyimur had both technical indications as well as local demand for direct use geothermal applications. In 2019, the Ugandan Ministry of Energy and Mineral Development prepared a detailed report on the status of the country’s most promising resources, where they included Panyimur among the most promising. Additional feasibility studies are planned.

III. INDUSTRY STAKEHOLDER CONSULTATIONS

This section provides a summary of the industry stakeholder consultations that were undertaken in each country. Due to the global COVID-19 pandemic, the GreenMax team's planned missions and all of the in-person meetings/workshops were canceled. As a result, an online group teleconference/webinar was prepared and delivered for local geothermal industry stakeholders in each country. Participants in these meetings included representatives from government, the geothermal industry, and other development partners. The purpose of the teleconference was to introduce these key stakeholders to the assignment, to present our preliminary findings, and to engage in discussions in order to better understand their perspectives and experience in the geothermal direct use sector. The teleconference included a brief presentation of our analysis, site selection approach, methodology and findings, followed by an open discussion/Q&A session with all participants.

The summaries presented below include a list of the stakeholders who participated in each meeting, the questions and comments that were raised during the Q&A session and any additional input and feedback from participants. Through follow-up correspondence, workshop participants were also able to assist with identification of local community representatives at the selected geothermal sites who could support the assignment's next phase of data collection (which is presented in **Section IV** of this report).

A. Djibouti

i. Workshop Participants

Name	Organization	Position / Title
Hezy Ram	GreenMax Capital Advisors	Team Leader
Umut Destegul	GreenMax Capital Advisors	Direct Use Expert
Dr. Peter Omenda	GreenMax Capital Advisors	Geoscientist
Barbara Kenya	GreenMax Capital Advisors	Social Scientist
Alexander LaBua	GreenMax Capital Advisors	Project Coordinator
Lena Ngure	GreenMax Capital Advisors	Project Coordinator
Abdourazak Ahmed Kayad	GreenMax Capital Advisors	Djibouti Local Expert
Dr. Meseret Teklemariam Zemedkun	United Nations Environment Programme	Senior Geothermal Expert
Idriss Ismael Nour	Ministry of Environment; Manager of the Environment and Sustainable Development Department	National Designated Entity (NDE)
Dr. Kayad Moussa Ahmed	ODDEG	General Manager
Abdek Mahamoud Abdi	ODDEG	Environmental Engineer
Nasteho Djama Houssein	ODDEG	
Farah Omar Farah	ODDEG	
Abdirazak Omar Moumin	ODDEG	
Samatar Hassan	ODDEG	
Isnino Ali	ODDEG	
Nasradin Ali	ODDEG	
Awo Mohamed	ODDEG	
Gouled Mohamed Djama	Ministry of Energy	Director of Energy
Said Kaireh Youssouf	Ministry of Agriculture, Water, Fisheries and Livestock	Director of Rural Hydraulic Department
Asma Mohamed Farah	Ministry of Agriculture, Water, Fisheries and Livestock	Rural Hydraulic Department
Mouktar Mahamoud Waberi	Ministry of Agriculture, Water, Fisheries and Livestock	Director of Agriculture and Forestry
Moussa Issack Farah	Ministry of Agriculture, Water, Fisheries and Livestock	Agricultural Statistics Engineer
Linda Youssouf Kayad	Ministry of Housing, Urban Planning and Environment	National Program Coordinator
Moustapha Hassan Ibrahim	Ministry of Higher Education and Research of Djibouti; University of Djibouti	Assistant Professor
Dr. Daha Hassan Daher	Ministry of Higher Education and Research of Djibouti; Djibouti Study and Research Center	Laboratory of Renewable and New Energies
Mohamed Egueh Walieh	Ministry of Higher Education and Research of Djibouti; Djibouti Study and Research Center	Chairman of PAIX ET LAIT Association
Fatima Elsheikh	United Nations Development Program (UNDP)	National Representative
Dademanao Pissang	UN Food and Agricultural Organization (FAO)	National Representative
Daher Elmi	Executive Secretary of the Intergovernmental Authority on Development (IGAD)	Project Manager, Natural Resources Management and Renewable Energy

ii. Workshop Summary

Questions/Comments/Recommendations	Feedback/Contributions/Responses
Name: Dr. Kayad Moussa Ahmed **Organization**: ODDEG **Question/Comment/Recommendation**: There is not enough data to thoroughly evaluate the sites. Additional technical discussions about the sites would be appreciated.	**Response**: Dr. Peter Omenda: The GreenMax team will share technical data and arrange for a follow up discussion with ODDEG as needed.
Name: Dr. Meseret Teklemariam Zemedkun **Organization:** UN **Question/Comment/Recommendation:** Very good presentation, happy to see Kayad's concern and understanding in connecting the different uses to community resources To Kayad: What about other low temperature areas such as Obok?	**Response:** Dr. Kayad Moussa Ahmed: Obok and Tadjourah also have potential for direct use applications, such as tourism (e.g. hot springs); Drilling water wells of 80°C for direct use are planned
Name: Dademanao Pissang **Organization:** FAO **Question/Comment/Recommendation:** Outcome from this project will be very useful for agricultural use, as farmers could benefit from utilizing geothermal heat for greenhouses to reduce electricity costs. Based on the outcome of this study, an assessment can be made accordingly for each rural community.	**Response:** Dr. Kayad Moussa Ahmed: Pasteurization and other applications such as fish drying could benefit from geothermal energy. Environmental and social studies need to be conducted to setup projects for local communities.
Name: Linda Youssouf Kayad **Organization:** Ministry of Housing, Urban Planning and Environment **Question/Comment/Recommendation:** Please share a copy of the technical report	**Response:** Alexander LaBua: A copy of the GreenMax team's report / technical analysis will be made available to all workshop participants
Name: Asma Mohamed Farah **Organization:** Ministry of Agriculture, Water, Fisheries and Livestock **Question/Comment/Recommendation:** If geothermal is an alternative for cheaper energy, what are some other applications of geothermal heat? E.g. for milk pasteurization etc.	**Response:** Hezy Ram: Geothermal energy can be utilized for both power generation as well as for heating / direct use applications Dr. Peter Omenda: For example, at Menengai, Kenya, water from the geothermal power plant is cycled through a heat exchanger and used to pasteurize milk, heat a greenhouse and a fish pond.

B. Ethiopia

i. Workshop Participants

Name	Organization	Position / Title
Hezy Ram	GreenMax Capital Advisors	Team Leader
Umut Destegul	GreenMax Capital Advisors	Direct Use Expert
Dr. Peter Omenda	GreenMax Capital Advisors	Geoscientist
Barbara Kenya	GreenMax Capital Advisors	Social Scientist
Alexander LaBua	GreenMax Capital Advisors	Project Coordinator
Lena Ngure	GreenMax Capital Advisors	Project Coordinator
Getnet Tesfaye	GreenMax Capital Advisors	Ethiopia Local Expert
Dr. Meseret Teklemariam Zemedkun	United Nations Environment Programme	Senior Geothermal Expert
Habtamu Denboba	Environment, Forest and Climate Change Commission	
Salahadin Ali	Geological Survey of Ethiopia	
Hundie Melka	Geological Survey of Ethiopia	Director, Geothermal Exploration and Assessment
Dr. Dejene	Geological Survey of Ethiopia	Chief Geologist
Mesfin Dabi	Ministry of Water, Irrigation and Energy	Director of Energy Policy, Strategy and Information Directorate
Tesfaye Kassa	Ethiopian Energy Authority	Director, Geothermal Directorate
Habtamu Abatneh	Ethiopian Energy Authority	Geothermal Compliance and Monitoring Expert
Andualem Ayele	Ethiopian Energy Authority	Geothermal Resource Development Licensing and Administration Directorate
Fikre Feleke	Ethiopian Energy Authority	Senior licensing and administration expert
Mikyas Bekele	Ethiopia Horticulture Producer Exporters Association	Head, Training Department
Getachew Adam Workneh	Addis Ababa Science and Technology University (AASTU)	Head, Center of Excellence in Sustainable Energy, College of Applied Science

ii. Workshop Summary

Questions/Comments/Recommendations	Feedback/Contributions/Responses
Name: Tesfaye Kassa **Organization**: Ethiopian Energy Authority **Question/Comment/Recommendation**: The country has a 10-year plan for geothermal development, including a five-year plan for direct use geothermal; this project will support the country's push to develop direct use projects. Geothermal development licensees can have a combined license (i.e. for power as well as thermal applications). The Abaya geothermal site is already under license – the licensees plan to develop it for both power and thermal applications.	**Response**: Hezy Ram: We normally don't look at high temperature geothermal resources for direct use applications because you can make electricity, which is more profitable. In some countries, high temperature resources are being utilized for direct use applications (e.g. in New Zealand), but this is not common. Umut Destegul: Sites were selected using pre-existing data and selection criteria. In some cases, there was a lack of / insufficient data available on direct use. In our analysis, the threshold for which sites could utilize direct use geothermal also covered high temperature resources due to the possibility of using cascading

Please describe how you classified the resources; did you review all 24 geothermal areas in the country?	systems. It is worth noting that this is only a pre-feasibility study, and our work can be used to guide further development of the sector.
Name: Salahadin Ali **Organization:** Geological Survey of Ethiopia **Question/Comment/Recommendation:** Do you think the projects risks for direct use geothermal projects will be similar to those of high temperature systems? What type of direct use applications would you think about in the three selected areas / what are the conclusions from your findings?	**Response:** Hezy Ram: There are two main types of risk - commercial and technical. Finding the resource for direct use is easier than for high-temperature/power projects use because it is more common, and wells can be shallower leading to decreased cost and time. Therefore, direct use has lower technical risk but higher commercial risk because there may not be much profit. You are not making electricity that is easy to sell and always in demand (issues of contracts). Alexander LaBua: Our team is still analyzing the surrounding communities at three selected sites to determine which applications are best suited for them.
Name: Tesfaye Kassa **Organization:** Ethiopian Energy Authority **Question/Comment/Recommendation:** What were the main criteria for selecting each geothermal site?	**Response:** Umut Destegul: We looked primarily into technical data that was already collected and analyzed. The availability of data also factored heavily into the weighted scoring / site selection approach.
Name: Dr. Meseret Teklemariam Zemedkun **Organization:** UNEP **Question/Comment/Recommendation:** Ethiopia has 24 sites with power generation but over 150 more sites that may be utilized for direct use/thermal applications. Direct use should be community based. There is ample low temperature data (including from boreholes drilled for potable water supply in Addis Ababa and other areas) and that because these areas are either in or around cities they could be used to develop direct use applications (bathing, recreation, etc.). These are important because they can be developed at low cost by local communities (also considering the fact that job creation is a top priority for the government).	Alexander LaBua: These are helpful suggestions; what we have prepared here is only a pre-feasibility study. Our work can be used as a baseline for future research and more comprehensive/technical feasibility studies of more sites throughout the country. Dr. Peter Omenda: Our work involved review of existing data. More studies should be undertaken to gather geological information of all types.
Name: Getnet Tesfaye **Organization:** GreenMax Capital Advisors **Question/Comment/Recommendation:** What happens if we do not get suitable demand for thermal applications close to the selected sites? Do we revisit the selection for the resources?	**Response:** Hezy Ram: We cannot develop a direct use project far away from the source of demand / user.
Name: Getachew Adam Workneh **Organization:** Addis Ababa Science and Technology University (AASTU) **Question/Comment/Recommendation:** We should connect the project with students from the university.	**Response:** Alexander LaBua: Well noted for collaboration

C. Kenya

i. Workshop Participants

Name	Organization	Position / Title
Hezy Ram	GreenMax Capital Advisors	Team Leader
Umut Destegul	GreenMax Capital Advisors	Direct Use Expert
Dr. Peter Omenda	GreenMax Capital Advisors	Geoscientist
Barbara Kenya	GreenMax Capital Advisors	Social Scientist
Alexander LaBua	GreenMax Capital Advisors	Project Coordinator
Lena Ngure	GreenMax Capital Advisors	Project Coordinator
Koye Alaba	GreenMax Capital Advisors	Project Analyst
Giulia Ferrini	CTCN	Associate Project Manager
Rajiv Garg	CTCN	Regional Manager
Dr. Meseret Teklemariam Zemedkun	United Nations Environment Programme	Senior Geothermal Expert
Kelvin Khisa	Kenya Industrial Research And Development Institute (KIRDI)	National Designated Entity (NDE)
Betty Rose	KIRDI	
Martha Mburu	Geothermal Development Company	Engineer - Direct Use Technology
Damaris Njoroge	KenGen	Planning Department
Chrispin Lupe	Ministry of Energy	Chief Geologist
Richard Mavisi Liahona	Ministry of Energy	Senior Geologist
Julius Kirima	Ministry of Industrialization	Deputy Director

ii. Workshop Summary

Questions/Comments/Recommendations	Feedback/Contributions/Responses
Name: Chrispin Lupe **Organization**: Ministry of Energy **Question/Comment/Recommendation**: What is the end goal of the project? Does the team intend to implement some infrastructure to be used by the community (if that is the case – concern raised on sites selected are already licensed to KenGen and GDC). As area is licensed to KenGen, it is critical that they approve of the project. Direct use is currently one of the issues identified in the new renewable energy act. Thus far it is unclear how things will progress in terms of licensing for direct use; e.g. whether it will follow the same processes as geothermal for power generation etc.	**Response**: Dr. Peter Omenda: Having worked closely with both KenGen and GDC, I am aware that both organizations have a plan to increase the utilization of direct use technologies beyond current levels. KenGen is thinking of developing an industrial park, which would help demonstrate the feasibility of direct use projects. GDC has also been planning to develop an industrial park and is currently piloting direct use geothermal projects (e.g. at Eburru). The participation of KIRDI in this discussion is also welcome, as direct use applications will require further research, which is an area where they can provide support to/partner with KenGen and GDC.
Name: Julius Kirima **Organization:** Ministry of Industrialization **Question/Comment/Recommendation:** Requested clarification on whether direct use will require diverting some of the steam or tapping it after power generation. An integrated use of geothermal would be the ideal way to proceed, with KenGen and other players involved in planning and development of both power generation and direct use. In this manner, we can provide the full	**Response:** Hezy Ram: Responding to the query on whether direct use is based on cascading system – taking affluents from the plant or hot water or steam directly from the ground. This is applicable to both technologies. An example would the geothermal power plant where the effluent prior to reinjections is used for drying of vegetables or for warming a fishpond etc.

opportunities that are available to channel investment towards the sector. E.g. steam for heating, drying. Please also comment on special economic zones, which are being planned.	Barbara Kenya: On special economic zones, there was an effort made to designate a special industrial zone within the Olkaria site. Even with the existing industrial zones, there is an opportunity that the Ministry of Industrialization and Kenya Association of Manufacturers, among others, can partner to reduce emissions and find alternative sources of energy through direct use geothermal. In the agricultural sector, in addition to greenhouse implementation, GDC has worked on milk processing, flower farms, fishponds and other direct use applications (e.g. crop planting and nurturing in the field, preservation in packing houses for longevity and preservation of nutrients as well as food processing and drying (cereals, grains, fruits)
Name: Dr. Meseret Teklemariam Zemedkun **Organization:** UNEP **Question/Comment/Recommendation:** The objective of the assignment is to identify resources, exclusively from low-to-medium temperature geothermal systems. However, from the approach/methodology and selection criteria for the three sites, high temperature geothermal systems are included – what was the rationale for using high temperature systems instead of reviewing low to medium systems (e.g. Baringo, Homa Bay and others)?	**Response:** Dr. Peter Omenda: One of the reasons there is a lack of progress in direct use development is that institutions are focusing more on electricity than on thermal/direct use applications. During a previous engagement with KenGen – they had requested analysis of the Olkaria and Eburru sites for potential cascading systems. Another challenge is the absence of a national master plan to guide direct use sector development (one of the key outcomes of this study is to better inform policymakers). Direct use is not properly licensed. Current licensing procedures focus on electricity generation. More feasibility studies also need to be undertaken on thermal demand (e.g. in industry and manufacturing). Hezy Ram: With respect to the site selection, this was discussed with KenGen, who indicated that their preference was for us to assess high temperature resources / licensed geothermal sites for potential direct uses. Other resources not under control of KenGen and GDC that are of low-to-medium temperature may require further study going forward. Umut Destegul: Our scope of work was limited to assessing available/existing data. The technical team conducted an extensive review of existing documents/reports. Additional data needs to be collected on low-to-medium geothermal resources.
Name: Giulia Ferrini **Organization:** CTCN **Question/Comment/Recommendation:** The objective of the technical assistance provided by CTCN is to respond to the request made by the Ministry. Would otherwise not make sense if there was no political will to use the results of the assistance. CTCN hopes that this study can be the first step in creating the awareness to make the case for medium and low temperature direct	

use applications by working with the relevant ministries to ensure recommendations are shared and lead to changes beneficial to the country.	
Name: Kelvin Khisa **Organization:** KIRDI **Question/Comment/Recommendation:** Recently, KIRDI published the National Climate Change Action Plan for 2018-2022 and the Green Economy Strategy and Implementation Plan (GESIP) for 2016 – 2030. These documents highlight the need for Kenya to pursue a low-carbon, efficient and socially inclusive development strategy. It would be interesting for the GreenMax team to see how they can integrate emerging concepts (e.g. in industry and energy sector development) into direct use of geothermal energy. It is possible that upcoming industrial parks are designed to be eco-industrial parks, so that they are energy efficient. This will help Kenya meet its commitments under the National Climate Change Plan as well as the priorities of GESIP. It would also be good to get further clarification on how local communities will be engaged/included in this study. From previous experience, communication and clarification is critical to ensure that the communities are adequately prepared to provide helpful feedback.	**Response:** Hezy Ram: Heat parks are technologies widely used across the world mainly to provide district heating with heat pumps in areas that have winter. Since the majority of countries in Africa do not use heat pumps, it's unlikely that heat parks would be really viable in this region (e.g. no use of boilers to heat homes during the cold season). Barbara Kenya: Although boilers are not used residentially, industrial boilers are used in Kenya. There is also a need to shift away from diesel fuels to meet air quality / emission standards, so direct use heat for industrial boiler utilization has potential. For communities – we will be administering community surveys. We are currently working to identify community representatives at the identified sites. The survey includes questions that address economic activities, consumer perceptions, and social/cultural aspects in each community. We will be considering direct use applications in areas such as food processing (e.g. drying of vegetables, fish), among others. Hezy Ram: The way cascading geothermal systems work – using Olkaria as example – steam and hot water are extracted from the ground; steam gets run through a flash tank separating steam and brine; steam is used to spin a turbine connected to generator, which is connected to the grid. The brine is usually reinjected into the ground. Under cascading, this brine can be used in a direct use application. When we use geothermal steam to heat other direct use applications, the efficiency of the heat transfer is about 80-90%, versus electricity conversion, where efficiency is about 20%. So direct use is a more efficient and environmentally friendly process.
Name: Martha Mburu **Organization:** GDC **Question/Comment/Recommendation:** At GDC one of the mandates from 2010 is to market and spearhead direct use technology. Over the last six years, GDC has demonstrated that direct use can positively impact the local communities nearby geothermal development sites. GDC has been trying to educate communities on direct use – which is why they set up the demonstration projects at Menengai that the community could benefit from (e.g. milk processing, green houses and aquaculture). In 2019, GDC set up another demonstration project at Menengai – a grain dryer that utilizes geothermal heat.	**Response:** Barbara Kenya: We would be happy to collaborate more closely with GDC on the next phase of our work, which will entail engagement with local communities by the selected sites.

This project has received significant attention. In Kenya, grain is typically dried under the sun; last year during harvest time, very heavy rains left farmers with losses of up to 60% of their crops. The grain dryer would eliminate this risk for farmers. In 2012-2015, GDC performed a comprehensive study producing a guide book on direct use geothermal, which examined how direct use projects could be scaled up to meet the economic needs / support the livelihoods of the people. GDC's current work is focused on getting an energy tariff for thermal energy for direct use. Thermal energy has previously not been costed in Kenya. GDC also has a fully-staffed community relations department.	
Name: Damaris Njoroge **Organization:** KenGen **Question/Comment/Recommendation:** Apologized on behalf of team members who could not participate due to other engagements.[133] With regards to data, KenGen could only provide guidelines on data that they have access to (i.e. their two licensed areas of Eburru and Olkaria). KenGen is keen on community engagement, as well as the opportunity to identify and develop direct use projects. KenGen also plans to deploy this technology in an industrial park, with the goal of ensuring it is a green project that aligns with the government's sustainable development agenda.	

[133] A follow up meeting was held with KenGen – in attendance were Peketsa Mangi, Cyrus Karingithi and Damaris Njoroge from KenGen; and Hezy Ram, Lena Ngure, Peter Omenda, Umut Destegul and Barbara Kenya from GreenMax. During the meeting, the workshop presentation was reviewed, expectations/next steps were clarified and guidance was provided by KenGen on stakeholder engagement at the community levels.

D. Rwanda

i. Workshop Participants

Name	Organization	Position / Title
Hezy Ram	GreenMax Capital Advisors	Team Leader
Umut Destegul	GreenMax Capital Advisors	Direct Use Expert
Dr. Peter Omenda	GreenMax Capital Advisors	Geoscientist
Barbara Kenya	GreenMax Capital Advisors	Social Scientist
Alexander LaBua	GreenMax Capital Advisors	Project Coordinator
Lena Ngure	GreenMax Capital Advisors	Project Coordinator
Larry Vincent Mpaka	GreenMax Capital Advisors	Rwanda Local Expert
Dr. Meseret Teklemariam Zemedkun	United Nations Environment Programme	Senior Geothermal Expert
Gilbert Haganje	Rwanda Energy Development Corporation Limited (EDCL)	Senior Engineer
Octave Vuguziga	Nyabihu Tea Factory	Manager
Eugene Karangwa	EDCL	Geothermal Reservoir Scientist
Herman Hakuzimana	REMA (Rwanda Environment Management Authority).	Director, Department of Climate Obligations
Apolinaire Twahirwa	REMA (Rwanda Environment Management Authority).	

ii. Workshop Summary

Questions/Comments/Recommendations	Feedback/Contributions/Responses
Name: Gilbert Haganje **Organization**: EDCL **Question/Comment/Recommendation**: What can you propose as direct use applications? What other direct use applications exist?	**Response**: Dr. Peter Omenda: Our study is not complete yet; we can provide more comprehensive examples once our engagement with the local communities has been completed. Hezy Ram: We provided only a few examples but many other applications exist such as fish drying and other applications specific to Rwanda (e.g. in Tobacco processing / leaf drying)
Name: Octave Vuguziga **Organization:** Nyabihu Tea Factory **Question/Comment/Recommendation:** I would like to inquire whether your research/study is examining direct use / heating applications for tea drying at a factory level (Nyabihu Tea Factory). How can we use this technology? We are near the Karago site which has around 73 degree hot water.	**Response:** Hezy Ram: Drying tea leaves is very common and can be looked into for the next phase of our work. Barbara Kenya: The heat exchange technology would work well.

E. Tanzania

i. Workshop Participants

Name	Organization	Position / Title
Hezy Ram	GreenMax Capital Advisors	Team Leader
Umut Destegul	GreenMax Capital Advisors	Direct Use Expert
Dr. Peter Omenda	GreenMax Capital Advisors	Geoscientist
Barbara Kenya	GreenMax Capital Advisors	Social Scientist
Alexander LaBua	GreenMax Capital Advisors	Project Coordinator
Lena Ngure	GreenMax Capital Advisors	Project Coordinator
Dr. Meseret Teklemariam Zemedkun	United Nations Environment Programme	Senior Geothermal Expert
Eng. Jacob Mayalla	Ministry of Energy	Principle Geologist
Eng. John Kitonga	EWURA (Energy and Water Utilities Regulatory Authority)	Electricity Inspector
Dr. Gerald Kafuku	COSTECH (Tanzania Commission for Science and Technology)	National Director
Lena Drabig	Energio Verda Africa	Tanzania project coordinator
Arthur Karomba	Energio Verda Africa	Tanzania Local Expert
Mwangi, Elizabeth N	CTCN	
Eng. Kato Kabaka	Tanzania Geothermal Development Company (TGDC)	General Manager
Shakiru Idrissa	TGDC	Assistant Director Business Development
Eng. Helena Sezar	TGDC	Direct use Engineer
Dr. Matthew Matimbwi	Tanzania Renewable Energy Association (TAREA)	Executive Secretary

ii. Workshop Summary

Questions/Comments/Recommendations	Feedback/Contributions/Responses
Name: Dr. Gerald Kafuku **Organization**: COSTECH **Question/Comment/Recommendation**: Have there been any direct activities onsite by GreenMax? Did GreenMax visit the site or will this be during the next phase?	**Response**: Alexander LaBua: The first phase of research concludes with this workshop. The next phase of our research is a site visit to engage with the communities around the project site of Kiejo-Mbaka.
Name: Dr. Matthew Matimbwi **Organization:** TAREA **Question/Comment/Recommendation:** Will you share the list of stakeholders you have identified for interview? We could recommend names if there are any missing on the list. Will you present the results to the stakeholders for validation? Who will be the final consumer of the study?	**Response:** Alexander LaBua: A preliminary list of stakeholders is existing which will be finalized together with TGDC. This can then be shared with the participants of this workshop for input. The results of our engagement at community level will be made available. The beneficiaries of the study will be at the government level (TGDC) and community and SME levels.
Name: Eng. Kato Kabaka, Shakiru Idrissa, Eng. Helena Sezar **Organization:** TGDC **Question/Comment/Recommendation:** What is the plan to accomplish the output for developing a tool and guideline for geothermal direct uses?	**Response:** Alexander LaBua: Once the analyses of all sites in each of the six countries are finalized there will be a capacity building workshop. A set of guidelines and recommendations will be shared for each country.

What are the project timelines? / Will the revised action plan be shared with proponents? What about the validation of workshop? How are we modifying work schedule?	Hezy Ram: Progress reports, tools and reports including recommendations and guidelines for direct uses will be prepared as part of our study. Alexander LaBua: Due to Covid-19 the timeline has been delayed. We intend to finalize the work before end of the year. The revised action plan will be shared with proponents. Alexander LaBua: Timing of the workshop is not known at this stage. Initially it was planned to have everyone travel to Nairobi for the workshop, but we may need to conduct the final workshop remotely due to international travel restrictions.
Name: Eng. John Kitonga **Organization:** EWURA **Question/Comment/Recommendation:** According to your analysis, Kiejo-Mbaka is suitable for what kind of use? Power Generation, Hot Springs, etc.? How long will it take to develop Kiejo-Mbaka to be used as a hot Spring for tourism or swimming? What are the costs of developing a hot spring?	**Response:** Dr. Peter Omenda: It has many potential uses and we are still investigating. It is good for power generation and direct use. It likely has many potential agricultural uses. Hezy Ram: Further study and working with partners needs to be done first. GreenMax will undertake this type of investigation in the next phase of the assignment. Eng. Kato Kabaka: Three stages of development are planned for Kiejo-Mbaka: 1. Drilling of shell wells to confirm resource for direct use 2. Implementation of direct use applications 3. Deep drilling for electricity use generation Currently at the procurement stage for shell drilling Hezy Ram: Cost estimates cannot be given at this stage, since we don't know the exact uses the and size Eng. Kato Kabaka: Cost will be established after the pre-feasibility report and the shell drilling
Name: Dr. Meseret Teklemariam Zemedkun **Organization:** UN Environment Programme **Question/Comment/Recommendation:** There is no doubt that GreenMax is addressing the needs and expectations of TGDC. But what was the main reason that Ngozi and Songwe were not considered in the study?	**Response:** Eng. Kato Kabaka: TGDC decided to apply for Kiejo-Mbaka only, because Songwe is already at an advanced stage of development. Swimming pool for hot bath is almost finalized and a chicken farm, a fishpond and a greenhouse are being planned as well. Kiejo-Mbaka is the next project for direct use therefore TGDC wanted to focus on this site.
Name: Eng. Jacob Mayalla **Organization:** Ministry of Energy **Question/Comment/Recommendation:** The Ministry is supporting this geothermal project and is very interested in seeing that the project will be implemented. And thank you to CTCN and GreenMax to assist TGDC in this for Tanzania's new resource.	**Response:** Alexander LaBua and Hezy Ram thank the Ministry for their support.

F. Uganda

i. Workshop Participants

Name	Organization	Position / Title
Hezy Ram	GreenMax Capital Advisors	Team Leader
Richard Kiggundu	GreenMax Capital Advisors	Project Consultant
Umut Destegul	GreenMax Capital Advisors	Direct Use Expert
Dr. Peter Omenda	GreenMax Capital Advisors	Geoscientist
Barbara Kenya	GreenMax Capital Advisors	Social Scientist
Alexander LaBua	GreenMax Capital Advisors	Project Coordinator
Lena Ngure	GreenMax Capital Advisors	Project Coordinator
Rajiv Garg	CTCN	Regional Manager
Dr. Meseret Teklemariam Zemedkun	United Nations Environment Programme	Senior Geothermal Expert
Godfrey Bahati	MEMD/Geothermal Resources Department	Commissioner, Geothermal Resources
Vincent Kato	MEMD/Geothermal Resources Department	Assistant Commissioner
Edward Isabirye	MEMD/Geothermal Resources Department	Senior Geologist
James Francis Natukunda	MEMD/Geothermal Resources Department	Geologist
Michael Ahimbisibwe	MEMD/Geothermal Resources Department	Acting Principal Energy Officer
Dr. Maxwell Otim Onapa	Ministry of Science Technology and Innovation	Director of Science, Research & Innovation
Dr. Callist Tindimugaya	Ministry of Water and Environment	Commissioner of Water Resources
Patrick Tushabe	Uganda Wildlife Authority	Product Development Executive
Isaac Ntujju	National Environment Management Authority	Principal Environment Inspector
Mr. Lauben Twinomujuni	Makerere University	Researcher, Biogeography and Geology
Faith Natukunda	Mbarara University of Science and Technology	Entrepreneurship Program Director
Isa Lugaizi	Geothermal Association of Uganda	Senior Geologist
Eric Byenkya	Bantu Energy Ltd	Chief Executive Officer
James Orima	Moto Geothermal Projekt Limited	Director
Fred Kabagambe-Kaliisa	Kibiro	Local Community Leader
Patrick Tushabe	Buranga	Local Community Leader
Ofoi Shaban Kinobe	Panyimur	Local Community Leader

ii. Workshop Summary

Questions/Comments/Recommendations	Feedback/Contributions/Responses
Name: Eric Byenkya **Organization**: Bantu Energy Ltd-Private Sector **Question/Comment/Recommendation**: Securing funding for projects is the toughest part. What sources of financing for geothermal direct use heat are easily available?	**Response**: <u>Hezy Ram:</u> There are several sources of funding in east Africa (can provide more sources at a later time through email). Icelandic development agency, European funding agencies, USAID/Power Africa, USTDA, AfDB will fund projects with social/community benefits (must have a great presentation to convince them).

	Private sector off takers can be potential users of the geothermal heat. Rajiv Garg: This study is the first step. The next step will include conducting a full feasibility study with technical, financing, markets aspects, etc. for specific projects. Projects will then be linked to the GCF Readiness Program. GCF will provide financing for disruptive technologies that can replace fossil fuels. A concept note to GCF will be drawn up as the next step to access GCF financing support. Project developers can contact CTCN/Rajiv directly for further details.
Name: James Orima **Organization:** Moto Geothermal Projekt Limited **Question/Comment/Recommendation:** Only three sites with the highest temperatures have been included in this study. Does Ihimbo have good temperatures for direct use with potential customers like tea factories? Feasibility studies have been conducted for Ihimbo, with resource temperatures of 90 degrees Celsius. a) What happens to other projects if they are not part of this round of technical assistance? Will they receive further assistance? b) Who would be willing to product test projects to prove that the industries would actually benefit communities?	**Response:** Rajiv Garg: This study was meant to identify projects/sites with a high potential for geothermal direct use. a) CTCN is happy to receive any applications for technical assistance for conducting full feasibility studies for other projects, b) Requests have to be submitted through the NDE. Alexander LaBua: Sites selected are only for pre-feasibility but there will be more studies in the future that will include more projects/sites. Hezy Ram: Emphasis on direct use applications has been outlined providing examples as to how the projects can benefit communities. The study covered sites with available data taking into account proximity to users. There have been limitations to the study due to the COVID-19 pandemic.
Name: Dr. Meseret Teklemariam Zemedkun **Organization:** UN Environment Programme **Question/Comment/Recommendation:** Policy should not be one of the barriers, the framework supported by CTCN in 2016 should be expedited including for direct use applications. The means that implementation is the biggest issue and removing barriers is necessary. Technical support is now available for direct use applications from the ARGeo facility. I agree with the selection process but why wasn't Katwe included (what rationale was used) for it is at the same level and has the same potential as the selected sites with industries that can utilize the geothermal heat. I agree with Rajiv Garg regarding the GCF financing concept. UNEP has signed an MOU with the Icelandic govt. while working with the GCF giving priority to low-medium temperature direct geothermal heat use. We are waiting for the outcome of this study to inform the next steps.	**Response:** Alexander LaBua: The selected methodology ranked top three sites for selection but that doesn't mean the fourth or fifth sites aren't feasible for future study. Umut Destegul: The analysis was conducted using 20+ indicators. The top five sites analyzed received similar scoring including Katwe. The analysis was done using data that was provided. If the data has been updated, the team will be happy to review the findings accordingly. Dr. Peter Omenda: What made the difference between the sites was if a TGW had been drilled at the site. The site then would score higher than the rest regardless of the potential. This explains why Kibiro which has had TGW drilled at the site recently, ranked the highest.
Name: Mr. Godfrey Bahati **Organization:** Ministry of Energy-Geothermal Resources Dept.	**Response:**

Question/Comment/Recommendation: The Buranga site has potential for drying crops, fish processing, pasteurization, etc. Government is investigating the site in Panyimur. The Panyigoro site is adjacent to Panyimur therefore the potential for geothermal could be quite big in this area. CTCN policy draft needs to be updated to reflect technical variations in the resource and therefore direct use potential (geothermal systems in the area are fault controlled rather than volcanic systems). Policy draft is to be presented by the Ministry of Energy to the cabinet for approval. Ihimbo and Panyigoro sites have quite a good potential. Eight wells have been drilled in Kibiro but will not continue as gas pockets were encountered which caused some damage to equipment. Drilling in this area will not be continued until an EIA has been completed. Kibiro has a very good potential as informed by the drilling done so far. Further drilling will be done at Panyimur.	
Name: James Francis Natukunda **Organization:** Ministry of Energy, Geothermal Resources Dept **Question/Comment/Recommendation:** The Katwe geothermal prospect should be selected as it has potential for tourism. It would be a good attraction for tourists being located inside a national park. It also has high potential for salt production.	**Response:**

IV. GEOTHERMAL DIRECT USE APPLICATIONS AND VIABLE PROJECTS IN THE IDENTIFIED LOCAL COMMUNITIES

This section presents information about the identified local communities that will benefit directly from the proposed geothermal direct use applications and respective projects in each country. Communities and SMEs located near the selected geothermal sites were identified with support from the Project Proponents in each country.[134] A survey was then administered to designated community/SME representatives to collect data in order to assess the commercial and technical viability of potential geothermal direct use projects (a copy of the survey can be found in **Annex 1**).

Utilizing feedback from the community engagement/surveys, the GreenMax team implemented a systematic approach to review the primary livelihood and economic activities in each community, identify areas of potential thermal demand that could benefit from geothermal heating applications, and categorize possible opportunities for direct use projects accordingly. A summary of the approach and methods used to categorize the direct use projects in each community – including the data sources used and any assumptions that were made where first-hand information was unavailable – can be found in **Annex 2**.

The method of survey administration varied by country. In some countries (namely, Djibouti, Kenya, and Tanzania), meetings were held in-person with local community representatives, while other countries (namely, Ethiopia, Rwanda and Uganda), could only engage with the communities through online/remote communications due to domestic travel restrictions associated with the global Covid-19 pandemic. The summaries presented below include a list of the stakeholders who participated in the survey activity, along with information about each of the identified communities and their respective potential geothermal direct use opportunities/projects.

[134] Only communities located near the selected geothermal resources were analyzed, as it is not feasible to benefit from geothermal resources far from the sources; it is essential to develop resources next to demand centers.

A. Djibouti

i. Identified Local Community Survey Respondents

In Djibouti, under the guidance and supervision of the Project Proponent, ODDEG, a mission was carried out to the three identified sites – Ambado PK20, Asal Fiale and Hanle Garabbayis.

Name	Position / Title	Community / Geothermal Site
Mohamed Ahmed Egueh	Maire adjoint	Ambado PK20
Saleh Hamahou Ali	Préfet adjoint	Assal Lake
Abdirahman Yonis Arreh	Conseil Régional de Dikhil	Hanle-Lac Abbe

ii. Assessment of Potential Geothermal Direct Use Applications in Identified Communities

Table 13: Categorization of Potential Geothermal Direct Use Applications in Djibouti

DJIBOUTI				
Geothermal Site	Community	Key Characteristics	Identified Geothermal Direct Use Application(s) in Community	Proposed Categorization and Rationale
Ambado PK20	Closest city of Djiboutiville is 25 km away	• Economic activities: Herding, cattle raring	• Milk Pasteurization • Meat Processing • Water desalination	**(1) Milk Pasteurization:** Cost of raw milk is 550 FDJ per litre and price of pasteurized milk is 550 FDJ per litre; demand for the export of pasteurized milk to Djiboutiville. **(2) Meat Processing: majority of the residents are herders and shepherds.** **(3)** Water Desalination: water for use in homesteads and livestock rearing. Potential to use geothermal for drinking water using trap condensation
Asal-Fiale	Closest city of Tadjourah is 75 km away	• Economic activities: Agriculture, aquaculture & tourism • Vegetables: Tomatoes, green pepper, salad, and onion • Fruits: Orange, mango, lemon, and guava	• Fruit & Vegetable Drying • Tea Processing • Greenhousing • Milk pasteurization • Honey processing • Meat processing • Desalination & irrigation of water • Balneotherapy	**(1) Fishing:** There is fishing activity in Goubet and Sougalou; ~200 fishermen with ~10 kg of fresh fish caught per month. High post-fishing loss due to lack of storage facilities and means of available of transport. However, there will be a new fishery in the town of Tadjourah which will have a large fridge. No demand for dried fish within the community, but it is sent to Yemen. Finding a market that consumes dry fish, a means of storage and transport are some of the listed barriers to growth **(2) Milk Pasteurization:** There is a demand for the export of pasteurized milk **(3) Balneotherapy:** Tourist sites in the district are White Sand, Randa, Fore de Day, Bankouale Doora, etc.; ~100 tourists per weekend in the winter. The region is easily accessible to tourists and has the availability of critical infrastructure. The community has also long been aware of the benefits of hot baths.
Hanle-Garabbayis	Closest city is Hanle-Dikhil about 50 kms away	• Economic activities: Agriculture, livestock, horticulture, tourism • Vegetables: lemon, onion, tomato, okra, cucumber, Chinese cabbage • Fruits: Watermelon, melon, mango, date, and hard valley papaya	• Fruit & Vegetable Drying • Tea Processing • Grain Drying • Greenhousing • Milk pasteurization • Honey processing • Meat processing • Desalination & irrigation of water • Balneotherapy	**(1) Milk Pasteurization:** There are no milk processing facilities in the area that could use the geothermal resource. The local consumption of pasteurized milk per household is 3 liters/day (90 liters per month). **(2) Balneotherapy:** Existing tourism sites are Abbot Lake, Handoga Walking Engraving, and Chaological Site near As Ela; ~100 tourists per weekend in winter. There is a hotel in Lake Abbe. The region is easily accessible to tourists, and the local community is very aware of the benefits of balneology

B. Ethiopia

i. Identified Local Community Survey Respondents

Name	Organization	Position / Title	Community / Geothermal Site
Mr Mebratu Gebre-Medhin Kora	Abela Abaya District Water, Mines and Energy Office	Energy Officer	SNNP region, Wolayita zone, Abela Abaya Wereda, Abaya geothermal field
Mr. Matusala Elias	Wolayita Zone Energy Office	Energy Works Coordinator	SNNP region, Wolayita zone, Abela Abaya Wereda, Abaya geothermal field
Mr. Yasin Hanfere Yasin	Afar, Water, Irrigation and Energy Office	Director of Water, Irrigation and Energy Office	Afar region, Zone 1, Dubti Wereda, Dubti geothermal field
Mr. Getnet Tesfaye	GreenMax Capital Advisors	Local consultant	Oromiya region, East Shewa zone, Adami Tulu Wereda, Aluto-Langano geothermal field

ii. Assessment of Potential Geothermal Direct Use Applications in Identified Communities

Table 14: Categorization of Potential Geothermal Direct Use Applications in Ethiopia

ETHIOPIA				
Geothermal Site	Community	Key Characteristics	Identified Geothermal Direct Use Application(s) in Community	Proposed Categorization and Rationale
Aluto-Langano	Gebeles 40-50 kms from Batu/Ziway and 100 kms from the nearest airport of Awasa	• Economic activities: smallholder farming, milk production and livestock farming, honey collection and processing • Fish: Whitefish, catfish, tilapia • Fruits: Avocadoes, papaya, mango, banana • Vegetables: Cabbage, green peppers • Grains: Barley, wheat, maize, millet, lentils, soybean, etc.	• Fruit & vegetable drying • Aquaculture and fish drying • Greenhouse heating • Milk pasteurization • Desalination of water and irrigation • Balneotherapy	**(1) Fruit & Vegetable Drying:** There are ~38,000 small farmers and an average plot size of 0.1 hectares. Cost of transporting fruits and vegetables to a geothermal source is ETB per trip for a 3-ton small truck. There is no fruit and vegetable drying station currently, existing demand for dried tomatoes and dried peppers **(2) Fishing:** Many fishing lakes around the geothermal site; ~2500 kg of fish is harvested by one fisherman per year and there are thousands of fishermen in the community. Post-harvest loss is high (>20%) due to lack of cold storage transportation. There is a demand for dried fish; poor technology and knowledge for drying are the challenges for increasing dried fish production **(3) Greenhousing:** There are many large flower farms in the area and strawberries are grown in green houses; a large existing greenhouse that can potentially utilize geothermal resources **(4) Milk Pasteurization:** No milk processing facility within 100 kms of a geothermal source. Low quality of milk and supply chain issues are some of the major barriers for increased milk production **(5) Balneotherapy:** There are a few tourist sites such as Lake Ziway, Lake Langano, Lake Abiyata. Area is well connected by roads and has accessibility to hospitals or banks; general awareness of balneotherapy in the community/region and its potential application as a tourist attraction
Dubti	460 kms from the city of Semera	• Economic activities: Irrigated farming, milk production and livestock farming • Fish: Whitefish, catfish, tilapia • Fruits: mangoes, papaya, oranges, avocados, watermelons, dates • Vegetables: lettuce,	• Aquaculture and fish drying • Milk pasteurization • Balneotherapy	**(1) Fishing:** About 250 kg of fish is harvested by one fisherman in a month and there are 25 fishermen in the community. Post-harvest loss is high due to lack of cold storage transportation; no fish drying station that can potentially utilize the geothermal resource. There is a demand for dried fish and the consumption is 15 kg/month. Poor technology and knowledge for drying stated as challenges for increasing dried fish production **(2) Milk Pasteurization:** No milk processing facility within 100 kms of a geothermal source. Estimated demand of milk per household is 90 litres/month. Low quality of milk due to poor genetic variation of cattle is one of the major barriers for increased milk production

		tomato, onion		**(3) Balneotherapy:** There are a few tourist sites such as Lake Loma, Lake Debaho, etc. Road accessibility is poor; no hospitals or banks; general awareness of balneotherapy in the community/region and its potential application as a tourist attraction
Abaya	SNNPR, Wolayita 75 kms away from the main city Wolayita Sodo	• Economic activities: small scale farming, livestock farming, aquaculture and small trades • Fish: Whitefish, catfish, tilapia • Vegetables: cabbage, tomato, onion, potato, carrot • Grains: maize, barley, sorghum, almonds,		(1) **Fruit & vegetable drying:** Post-harvest loss is due to lack of transportation and road facilities; no fruit and vegetable drying station currently in the community however there is a demand for it; 15kg/month for dried fruits and 30 kg/month for dried vegetables **(2) Fishing:** There is a waterbody within 100 kms of the geothermal source; ~2000 kg of fish harvested by one fisherman in a month. There is an existing fish drying station that can potentially utilize the geothermal resource. There is a demand for dried fish in the local community; consumption is 20 kg/month. Poor technology and knowledge for drying stated as challenges for increasing dried fish production **(3) Milk Pasteurization:** Abaya and Abela farms are two milk processing farms within 100 kms of a geothermal source. Estimated demand of milk per household is 30 litres/month. Low quality of milk due to poor genetic variation of cattle **(4) Balneotherapy:** There are a few tourist sites such as Lake Abaya, Abaya Hot Springs and Abela Reserved Forests. Road accessibility is poor.

C. Kenya

i. Identified Local Community Survey Respondents

Two separate meetings were held with local community representatives in Kenya. The first meeting took place in Naivasha with local community representatives from the Eburru and Olkaria geothermal sites. A second meeting was held in Nakuru with local representatives from the Olrongai community at the Menengai geothermal site. During each meeting, GreenMax Senior Consultants, Lena Ngure and Barbara Kenya, shared information with participants about geothermal direct use applications and administered the surveys. A list of community participants / survey respondents is included below.

Name	Organization	Position / Title	Community / Geothermal Site
Chief Benson N. Nganga	Gok community, Gilgil, Nakuru County	Chief	Gilgil / Eburru
Chief Hussein J Guyu	Gok community, Gilgil, Nakuru County	Chief	Gilgil / Eburru
Monicah Sakayian	Rapland community	Community Leader	Rapland / Olkaria
Joseph Torinke	Narasha Youth Group	Community Leader	Olkaria
Peter Suyangah Nkamasiai	Oloongot Community	Pastor	Olkaria / Eburru
Florence Tangaro	Olomayiana Kubwa community	Community Leader	Olkaria / Eburru
Lydiah Hyota	Eburru community	Community Leader	Olkaria / Eburru
Purity W. Nderi	Kamere Village	Community Leader	Olkaria / Eburru
Mwangi Sururu	Olomayiana Ndogo	Community Leader	Olkaria / Eburru
Philip Sekento Kenkan	KenGen	Community Liaison	Olkaria / Eburru
Hussein Jatani Gayi	Olkaria-	Administrative Chief	Olkaria / Eburru
Haron S. Kiraison	KenGen	Community Liaison	Olkaria / Eburru
Chief Reuben Omondi	Olrongai community	Senior Chief, Olrongai	Olrongai Sub Location / Menengai
Asst. Chief Betty Langat	Olrongai community	Assistant Chief, Olrongai	
Peter Otieno	Olrongai community	Upper Olrongai Nyumba Kumi elder	
Paul Yegon	Olrongai community	Resident	
Rose Maru	Olrongai community	Resident	
Henry Chakaya	Olrongai community	Village elder	
Henry Kuria	Olrongai community	Village elder	

GreenMax Senior Consultants, Barbara Kenya (far right) and Lena Ngure (not pictured) lead a discussion in Naivasha, Kenya with local community representatives from the Eburru and Olkaria geothermal sites

GreenMax Senior Consultants, Barbara Kenya (center) and Lena Ngure (not pictured) lead a discussion in Nakuru, Kenya with local representatives from the Olrongai community the Menengai geothermal site

ii. Assessment of Potential Geothermal Direct Use Applications in Identified Communities

Table 15: Categorization of Potential Geothermal Direct Use Applications in Kenya

KENYA				
Geothermal Site	Community	Key Characteristics	Identified Geothermal Direct Use Application(s) in Community	Proposed Categorization and Rationale
Olkaria	Kamere, Olomaiyan and Rapland Villages	• Economic activities: Small scale agriculture • Fish: Tilapia, common carp • Vegetables: Kale, cabbage, potatoes • Grains: Maize, beans, cabbage	• Fruit and Vegetable drying • Grain Drying • Aquaculture & Fish Drying • Meat Processing • Balneotherapy • Desalination of water • Chicken Hatcheries	**(1) Grain & vegetable drying:** Small land size is a challenge for agriculture; maize averages 5 acres; Kamere has even smaller plot sizes at <1 acre. **(2) Fish Drying & Refrigeration:** Post fishing loss is high; demand for dried fish in larger towns such as Bungoma and Nairobi **(3) Meat Processing:** Cows are generally reared for meat and not for milk production with the exception of Kamere where there is small scale milk production **(4) Desalination of water:** Potential to use geothermal for drinking water using trap condensation **(5) Chicken Hatcheries:** Currently there are 2 hatcheries in the area. These are some of the largest hatcheries in the country. Dryer in hatcheries instead of using electric steam leading to a cheaper process cost and eventually lower price for rearing chicken
Eburru	Gilgil Village	• Economic activities: Small scale agriculture and commercial farms for pyrethrum • Vegetables: potatoes, tomatoes, pyrethrum (98% of the community) • Grains: wheat, maize	• Pyrethrum Drying expansion • Grain Drying • Milk Pasteurization • Irrigation & desalination of the water • Chicken Hatcheries • Pottery • Balneotherapy	**(1) Grain & Pyrethrum Drying:** Farmers currently utilizing pyrethrum dryer that uses Fumaroles. Dryer has a current capacity of 2 tonnes versus demand of 8 tonnes. Wheat and maize are other largescale crops cultivated in the area. **(2) Milk Pasteurization:** Livestock rearing is mainly for milk. Farmers get about 7-8 litres from 2-4 cows. Potential for co-operative pasteurization through geothermal direct use **(3) Chicken Hatcheries:** Dryer in hatcheries instead of using electric steam leading to a cheaper process cost and eventually lower price for rearing chicken. **(4) Pottery:** Intension to start a ceramics and tiles manufacturing; potential to utilize the pottery raw material to make building bricks as well as the inner lining for efficiency charcoal burning jikos like the existing project in Kiambogo **(5) Irrigation & water desalination:** Potential to use geothermal for drinking water using trap condensation. Extremely erratic rainfall in area, water for consumption and agriculture is a huge challenge.

Menengai	Olrongai Village	• Economic activities: Small scale agriculture, flower farms and livestock farming • Vegetables: tomatoes, bell peppers, avocadoes • Fruits: oranges, pawpaw's, apples, guavas, macadamia, bananas	• Grain Drying • Greenhousing • Milk Pasteurization • Irrigation & desalination of the water • Balneotherapy	**(1) Grain (maize) drying:** Storing & drying maize would definitely be a huge direct use application as maize is harvested and sold directly to middlemen reducing profits. **(2) Milk Pasteurization:** Milk production is on a small- scale basis with an average of one milk-producing cow per household; two local milk processing sites and one in Nakuru. **(3) Irrigation & water desalination:** Current water supply in the area is not sufficient. Current water supply is mainly from Bahati/Kabarak and rain water. During dry season farmers have to source for water to buy. Standard fee of piped water is 500/- per month irrespective of whether water is received or not. **(4) Balneotherapy:** There are a few tourist sites such as a crater hike, bird watching, etc.; general awareness of balneotherapy in the community/region and its potential application as a tourist attraction

D. Rwanda

i. Identified Local Community Survey Respondents

Name	Organization	Position / Title	Community / Geothermal Site
Garuru Jean Baptiste	UCOP – Rubaru		Ginseyi Hot Spring
Jean D'Amour Niyontezeze	Mukamira Dairy Ltd		Karago Hot Spring
Octave Vuguziga	Nyabihu Tea Factory	Operations Manager	Karago Hot Spring
Robert Muhirwa	District Official	Executive Secretary	Karago Hot Spring

NOTE: No data was available for the Bugarama site during the timeframe of this study.

ii. Assessment of Potential Geothermal Direct Use Applications in Identified Communities

Table 16: Categorization of Potential Geothermal Direct Use Applications in Rwanda

RWANDA				
Geothermal Site	Community	Key Characteristics	Identified Geothermal Direct Use Application(s) in Community	Proposed Categorization and Rationale
Bugarama	No data	No data	• Aquaculture & Fish Drying • Tea leaf drying	**(1) Fishing drying** **(2) Tea leaf drying** No information was available at the time of this study related to local demand. This categorization therefore reflects our best estimate as to the DU applications which may be applicable to this site.
Ginseyi		• Economic activities: Small scale agriculture, aquaculture • Fish: Tilapia, sambaza • Vegetables: Tomatoes • Grains: Beans	• Aquaculture & Fish Drying • Balneotherapy	**(1) Fishing:** Lake Kivu is within 100 km of the geothermal site; 364 fishermen in the community each harvesting about 72 kg of tilapia per month and 8000-9000 of other small fish per month. Post-harvest loss of fish is high; no fish drying facility; a cooperative tried to start one but failed **(2) Balneotherapy:** In Rubavu there are currently two small hot springs local attraction sites.
Karago	Karago Nyabihu	• Economic activities: Small scale agriculture, livestock farming • Vegetables: tubers, carrots, cabbage • Grains: Maize • Economic activities: Small scale agriculture • Vegetables: tubers, carrots, potatoes, tea	• Milk Pasteurization • Tea Drying	**(1) Milk Pasteurization:** 12 milk collection centers but there are no large-scale commercial dairy producers; a milk processing facility in the area that can utilize geothermal resources. There is export demand for pasteurized milk of up to 90,000 litres per month. High cost of energy in processing and transportation listed as one of the barriers to higher exports **(2) Tea Drying:** 1 Tea factory in the Area Nyabihu Tea factory. About 5,000 tea farms in the area. About 25,000 Kg of tea processed daily. There is export demand for processed tea. Barriers to higher exports include costs of transportation, long distance traveled and taxes.

(3) Tanzania

i. Identified Local Community Survey Respondents

Name	Organization	Position / Title	Community / Geothermal Site
Maganga H Mwanahawa	Busokelo District Council	District Agriculture, Irrigation and Cooperative Officer (DAICO)	Kiejo Mbaka
Aruda Sinzo Mlulo	Busokelo District Council (Environment & Tourism Group)	District Land and Natural Research Officer (DLNRO)	
Agnes F. Elikunda	Busokelo District Council (Social & Gender Group)	District Community Development Officer (DCDO)	
Dr. Anania Lawrence Sangwa	Busokelo District Council (Livestock and Fisheries Group)	District Livestock and Fisheries Development Officer (DLFDO)	

In Tanzania, a mission was undertaken to the Kiejo-Mbaka site under the guidance and supervision of the Project Proponent, Tanzania Geothermal Development Company (TGDC). The individuals listed above captured the information provided by the villagers in the various communities visited during the mission.

ii. Assessment of Potential Geothermal Direct Use Applications in Identified Communities

Table 17: Categorization of Potential Geothermal Direct Use Applications in Tanzania

TANZANIA				
Geothermal Site	Community	Key Characteristics	Identified Geothermal Direct Use Application(s) in Community	Proposed Categorization and Rationale
Kiejo-Mbaka	Busekolo District Council, Ilamba Village 94 kms away from the nearest airport	• Economic activities: Small scale agriculture, aquaculture, livestock farming • Fish: Tilapia, catfish • Vegetables: spinach, tomato, amaranth • Fruits: Watermelon, pawpaws, oranges, mangoes, avocado • Grains: maize, cocoa, rice, beans • Etc.	• Fruit & vegetable drying • Tea Processing • Aquaculture & fish drying • Grain drying • Milk pasteurization • Meat processing • Irrigation • Balneotherapy	**(1) Fishing:** Many natural lakes (Lake Nyasa), volcanic lakes (Ikapu, Masoko, etc.) and rivers (Lufilyo, Mwalisi, etc.) within 100 km of the geothermal site; 700-1200 fishermen in the community each harvesting about 90-150 kg of fish a month. Post-harvest loss is high because of no cold storage chain to transport fish to the market; only way of drying is by sun-drying with a demand for dried fish even in the local community of about 15 kg per month per family **(2) Tea Processing:** There are 3219 tea farmers covering an area of 2933 hectares; with an existing tea factory in the area; poor infrastructure is the main barriers for export **(3) Greenhousing:** Tomatoes and onions are grown in greenhouses; preference for fruits and vegetables grown in greenhouses; one greenhouse (8x30 metres) that can use geothermal resources **(4) Milk Pasteurization:** One big ranch called Kitulo ranch producing 1500 litres of milk per day; 18,000 households each producing about 11 litres of milk per day; local consumption of milk is 30 litres/month per household. There aren't enough milk processing facilities in the area to meet the demand of pasteurized milk in the area **(5) Balneotherapy:** There are a few tourist sites and about 300 tourists visit the area every year. There are a few hotels and resorts in the area and the area is well connected by roads

(4) Uganda

i. Identified Local Community Survey Respondents

Name	Organization	Position / Title	Community / Geothermal Site
Patrick Tushabe	Uganda Wildlife Authority	Product Development Executive	Semuliki National Park, Buranga
Katusabe Alex	Bunyoro Kitara Kingdom	Chief Administrative Secretary Bunyoro Kitara Kingdom	Hoima District, Kibiro
Berocan Jimmy	Pakwach District Local Government	Fisheries Officer	Pakwach, Panyimur
Jenifer Oweka	Pakwach District Local Government	District Environment Officer	Pakwach, Panyimur

ii. Assessment of Potential Geothermal Direct Use Applications in Identified Communities

Table 18: Categorization of Potential Geothermal Direct Use Applications in Uganda

UGANDA				
Geothermal Site	Community	Key Characteristics	Identified Geothermal Direct Use Application(s) in Community	Proposed Categorization and Rationale
Kibiro	Hoima District About 20 kms from Hoima town	• Economic activities: farming, fishing, salt mining and livestock farming • Fish: tilapia, nile, perch, catfish • Fruits: pawpaws, mangoes and oranges • Grains: maize, sorghum, millet and sunflower	• Fish drying & Fish refrigeration • Grain drying • Tea processing • Greenhousing / fruit and vegetable processing	**(1) Fish drying & Fish refrigeration:** There are thousands of small fishermen in the area (Lake Albert); currently utilize sun-drying; post-harvest loss due to poor processing capacity and no cold storage chain to transport fish to the market; local demand for dried fish (estimated 2 kg/month per family) as well as for export outside of the community **(2) Grain (rice) drying:** Rice is grown by ~50,000 smallholder farmers in the surrounding community; currently utilize sun-drying on tarpaulins laid on the ground; post-harvest losses are high; local demand for rice (estimated 5 kgs/month per family) **(3) Milk Pasteurization**: There are ~10,000 small milk producers and about 10 large milk farms (>10 acres in size) in the surrounding area; there is a milk processing facility in the community that can utilize the geothermal resource; local milk consumption is ~8 liters/month per household; quality of milk produced is low and local production cannot meet demand for export **(4) Balneotherapy**: A few tourist sites located near hot springs, salt mines and a game reserve with about 20,000-50,000 tourists visiting each year; several hotels in the area and the area easily accessible by road; general awareness of balneotherapy in the community/region and its potential application as a tourist attraction **(5) Tea Processing**: there are two tea growing estates and one tea factory in the community that can utilize geothermal heat for tea processing (withering and drying); existing tea factories are 80 km from geothermal resource; poor infrastructure identified as main barrier for exporting tea **(6) Greenhousing**: Sunflowers and tomatoes are grown in greenhouses in the region; fruits and vegetables grown can also be grown/processed in greenhouses (i.e. to reduce post-harvest losses) but currently little/no local demand; most fruits and vegetables are consumed fresh, as the region has two natural planting/growing seasons
Buranga	Semuliki National Park	• Economic Activities: Subsistence farming, fishing, livestock farming, cultivation	• Fruit and vegetable drying • Drying tea leaves • Aquaculture & fish drying • Grain drying	**(1) Fish drying & refrigeration** There are is a water body within 100 km of the geothermal site. Post-harvest loss of fish is high because of poor handling of fish and no cold storage chain to transport fish to the market. Only way of drying the fish is by sun-drying and small local kilns;

	150 kms away from Kasese Airfield and 60 kms away from Toro Semliki Wildlife reserve airstrip	of cash crops, fish drying, balneotherapy related tourism • Fish: Tilapia, nile perch, catfish • Fruits: citruses, mangoes, passion fruit, avocadoes, jackfruits, apples, bananas • Vegetables: cabbages, onions, green leafy vegetables • Cash Crops: cocoa, vanilla, coffee	• Greenhouse heating • Milk pasteurization • Meat processing • Desalination of water, • Irrigation • Balneotherapy (hot springs/spa) • Electricity	demand for dried fish even in the local community of about 30 kg per month per family **(2) Grain (rice) drying:** Rice is grown only on small pieces of land of about ½ to 1 acre in size. 20-30% of yield is lost in pre & post-harvest loss; only sun-dried on tarpaulins laid on the ground. Local demand for rice is 60 kgs per month per family **(3) Milk Pasteurization:** There are many small milk producers and located over 70 kms away from the geothermal source. No milk processing facility is available nearby; local consumption of milk is 30 litres/month per household. **(4) Balneotherapy:** There are a few tourist sites around hot springs including those for bird watching with about 16,000 tourists visiting every year. There are currently no hotels in the area, but the area is easily accessible by road; general awareness of balneotherapy in the community/region and its potential application as a tourist attraction **(5) Tea Processing:** Many small farms (~1 acre) over an area of 500 acres; existing tea factories in the area but they are more than 80 kms away from the geothermal source. Monthly demand per family is 70 teabags per week. Poor infrastructure is a main barrier for exporting tea **(6) Greenhousing:** No fruits or flowers are grown in greenhouses in the region; demand for greenhouse grown fruits and vegetables if they were available off season and would be of better quality. There is no greenhouse in the area.
Panyimur	Pakwach District	• Economic activities: Farming, aquaculture and fish processing, food processing, milk pasteurization, honey extraction and processing, horticulture and poultry farming • Fish: Tilapia, catfish • Fruits: mangoes, jute melon, oranges • Vegetables: pumpkins, cowpeas, amaranth, okra, eggplants and tomatoes	• Drying vegetables and fruits • Processing tea leaves • Aquaculture & fish drying • Grain drying • Greenhouse heating • Milk pasteurization • Meat processing • Balneotherapy	**(1) Fish drying & refrigeration :** There are is a water body within 100 km of the geothermal site; >10,000 small fisherman in the Packwach district. (2) Post-harvest loss of fish is high because of poor handling of fish and no cold storage chain to transport fish to the market; sun-dried and in locally made kilns. There is a demand for dried fish even in the local community as well as for export; inappropriate drying facilities and low quality are the reasons for barriers to growing the market. **(3) Grain (rice) drying:** Average yield per plantation is 1500 kgs per year. Postharvest loss is high due to inappropriate drying methods and lack of mechanical facilities; only sun-dried on tarpaulins laid on the ground. **(4) Milk Pasteurization:** Quality of milk produced is low and local production cannot satisfy demand for export **(5) Balneotherapy:** There are a few tourist sites such as cultural sites, Lake Rubi-Kitang, museums, etc. with about 100 - 150 tourists visiting every year; no hotels and no roads in the area; general awareness of balneotherapy in the community/region and its potential application as a tourist attraction

ANNEX 1: LOCAL COMMUNITY SURVEYS

The survey below was administered to various representatives from the local communities at the identified geothermal sites in each country. Feedback from these surveys was used to assess the commercial and technical viability of geothermal direct use projects for each community.

I. OVERVIEW OF DIRECT USE APPLICATIONS:

1. What are the agricultural activities in the area? Please list all that apply.

2. Are the agricultural activities for domestic consumption or commercial purposes?

3. What are the typical economic activities, occupations and sources of income for residents in the area? What is the typical monthly/annual household income?

4. Please describe the main demographic characteristics of residents in the area (age, gender, household size etc.)?

5. What are the potential geothermal direct uses in your community (select all that apply):

   ☐ Drying vegetables/fruits/tea leaves – please specify ....

   ☐ Aquaculture – please state the types of fish ....

   ☐ Fish drying

   ☐ Grain drying

   ☐ Greenhouse heating – please specify the crops ....

   ☐ Milk pasteurization

   ☐ Meat Processing

   ☐ Desalination of water

   ☐ Production of irrigation water

   ☐ Balneotherapy (hot springs/spa)

   ☐ Others (please specify) ....

6. From the selected technologies (response to #5), please provide estimated quantities of raw material crops produced (if applicable):

   ....

   ....

....

7. If the geothermal direct use projects/technologies listed above are implemented, what would be the expected impact on:

   Marketing of the produce?

   ☐ No change

   ☐ Slight improvement in marketing (still limited to local area)

   ☐ Major improvement in marketing (extended beyond the local area)

   Price of the commodity?

   ☐ No change

   ☐ Slight improvement in price (based largely on better preservation of produce)

   ☐ Major improvement in price (based on expanded business opportunity beyond the local area)

8. Is demand expected to increase when the above technologies are adopted?

   ☐ No change in demand

   ☐ Moderate increase in demand

   ☐ Large increase in demand

II. SELECTED DIRECT USE APPLICATIONS:

2.1 FRUIT / VEGETABLE DRYING

1. What are the most common fruits and vegetables produced in the community?..........................

2. Estimate the number of fruit and vegetable farms within 100 km radius of the geothermal resource..........................
   How large are these farms on average (sq. km)?

3. Describe/estimate the levels of post and pre-harvest losses, as well as the main causes of these losses. What are the impacts associated with these losses?

4. Estimate the cost of transporting fresh fruits and vegetables to the geothermal resource..........................

5. What is the estimated cost of common fresh fruits (per Kg) .... cost of common fresh vegetables (per Kg) ....

6. Is there any existing fruit and vegetable drying station in the community that can potentially utilize the geothermal resource?

7. Is there demand for dry fruits and vegetables in your country (outside of your local community)? ......Yes / No.......
   If yes, please specify which types of fruits and vegetables: ....

8. What is the estimated level of consumption of dried fruits and vegetables for a typical household in your community (kg/month) ....

9. If possible/available, estimate the export demand for dry fruits/vegetables (kg/month) ....

10. Estimated price of dried fruits and vegetables (per Kg) .... include local and export market data (if available)

11. What are some of the key barriers / challenges associated with exporting dry fruits/vegetables?

2.2 <u>FISH DRYING</u>

1. What is the estimated cost of fresh fish (per Kg) ....

2. Estimated price of dry fish to be sold (per Kg) .... include local and export market data (if available)

3. Is there any water body with fishing activity within 100km radius of the geothermal resource?

4. Estimate the number of fishermen in the community .... Estimate the volume of fresh fish harvested by a typical fisherman (kg/month)?

5. Describe/estimate the levels of fishery losses, as well as the main causes of these losses. What are the impacts associated with these losses?

6. Estimate the cost of transporting fresh fish to the geothermal resource..........................

7. Is there any existing fish drying station in the community that can potentially utilize the geothermal resource?

8. Is there demand for dry fish in your country (outside of your local community)? ......Yes / No.......
   If yes, please specify which types of fish: ....

9. Estimate the level of demand/consumption of dry fish for a typical household in your community (kg/month) ....

10. If possible/available, estimate the export demand for dry fish (kg/month) ....

11. Estimated price of dried fish (per Kg) .... include local and export market data (if available)

12. What are some of the key barriers / challenges associated with exporting dry fish?

2.3 <u>GRAIN (RICE) DRYING</u>

1. What is the estimated cost of freshly harvested rice (per Kg)? ....

2. Estimate the number of rice plantations within 100 km radius of the geothermal resource..........................

3. How large are these plantations on average (sq. km)? What is the yield of a typical rice plantation per year (Kg)

4. Describe/estimate the levels of post and pre-harvest losses, as well as the main causes of these losses. What are the impacts associated with these losses?

5. What rice drying methods are currently being utilized in the community? What are the current costs of rice drying (per Kg)?

6. Estimate the cost of transporting freshly harvested rice from plantations to the geothermal resource......................

7. Is there any existing mechanical rice drying station in the community that can potentially utilize the geothermal resource?

8. Is there demand for rice in your country (outside of your local community)? ......Yes / No.......

9. Estimate the level of demand/consumption of rice for a typical household in your community (kg/month) ....

10. If possible/available, estimate the export demand for rice (kg/month) ....

11. Estimated price of dry rice to be sold (per Kg) .... include local and export market data (if available)

12. What are some of the key barriers / challenges associated with exporting rice?

2.4 <u>TEA DRYING</u>

1. What is the estimated cost of fresh harvested tea leaves (per Kg) ....

2. Estimate the number of tea leaf farms within 100km radius of the geothermal resource .... How large are these farms on average (sq. km)?

3. Is there any existing tea factory in the community that can potentially utilize the geothermal resource?

4. What is the estimated cost of transporting fresh tea leaves to existing tea processing facilities (per Kg)...................

5. What is the estimated price of processed tea (per Kg) .... include local and export market data (if available)

6. What is the estimated level of local consumption of locally processed tea per household (tea bags/week) ....

7. Is there export demand for processed tea? Estimated export demand for processed tea (kg/month) .... (if available)

8. What are some of the key barriers / challenges associated with exporting tea?

2.5 GREENHOUSES

1. What are the typical flowers grown outdoors in the region?..........................

2. What are the typical fruits, vegetables and flowers grown in greenhouses in the region?..........................

3. Is there particular demand for greenhouse produce over outdoor produce in your local community and in your country in general? ....Y/N............. Are households willing to pay more for greenhouse produce?

4. Is there any existing greenhouse in the area that can potentially utilize the geothermal resource? How big is this existing greenhouse?

5. What is the estimated level of demand for a typical household in the community for the different types of greenhouse produce (kg/month) ....

6. What is the estimated level of export demand for the different types of greenhouse produce (kg/month) .... (if available)

7. What are the estimated selling prices of typical greenhouse crops (per Kg) .... include local and export market data (if available)

8. Estimate / provide the cost of acquiring land in the region for setting up a greenhouse.

2.6 MILK PASTEURIZATION

1. What is the estimated cost of raw milk (per liter) .... Include data for large scale commercial diary producers and small holder producers (if available)

2. Estimate the number of farms producing raw milk within 100km radius of the geothermal resource........................
   How many of these are large scale commercial dairy producers and small holder producers? How big are the large scale and small scale farms respectively on the average?

3. Estimate the cost of transporting raw milk to existing milk processing facilities (per liter)..........................

4. Is there any existing milk processing facility in the area that can potentially utilize the geothermal resource?

5. Estimate the price of pasteurized milk (per liter) .... include local and export market data (if available)

6. Estimate the level of local consumption of locally pasteurized milk per household (liters/month) ....

7. Is there export demand for pasteurized milk? Estimated export demand for pasteurized milk (liters/month) .... (if available)

9. What are some of the key barriers / challenges associated with exporting pasteurized milk?

2.7 BALNEOTHERAPY (HOT SPRINGS)

1. What activities do households in the community engage in for leisure during weekends and holidays?
2. How much can households in the community comfortably afford to spend for relaxation in a month or year?
3. What are the existing tourism products (sites) and estimated number of tour companies in the district? Amounts tourists are charged at these sites.
4. Estimate the number of tourist visits to the area annually.
5. Are there any existing hotels/resorts in the area that can potentially utilize hot springs?
6. Is the area easily accessible for tourists by a good network of roads?
7. What is the level of local awareness of the benefits of warm bathing and balneology?
8. Availability of essential infrastructures such as banks, hospitals, telecommunication coverage etc. in the area.
9. How far is the geothermal resource from the main city with airport?
10. Estimate / provide the cost of acquiring land in the region for setting up a spa.

2.8 SOCIAL AND GENDER QUESTIONS

1. Please describe the typical social structure/hierarchy within a typical household. Are households predominantly run by men or women?

   ☐ Men

   ☐ Women

   ☐ Both genders equally

2. Please describe the role of gender with regards to land ownership. Do men and women have equal access and opportunity to own land?
3. Please describe the role of gender with regards to access to credit. Do men and women have equal access to credit? Please specify whether this is from a financial institution and/or from informal sources of financing.
4. Are men or women typically more heavily engaged in agricultural / farming activities?

   ☐ Men

   ☐ Women

☐ Both genders equally

5. What kind of economic activities do women engage in and what women-led activities can be supported by geothermal direct use solutions? Please check all that apply.

☐ Agriculture (food processing, fruit/vegetable drying)

☐ Aquaculture and fish drying

☐ Greenhousing

☐ Tourism (balneotherapy)

☐ Other (please specify)

6. What mechanisms or approaches are in place (if any) to raise community awareness about direct-use geothermal applications and their potential benefits? Are community meetings held on a regular basis and do women also participate in these meetings?

7. Are there any related programs or initiatives (government, donor, private sector, NGO etc.) that specifically aim to build the capacity/develop the skills of women in these areas (e.g. food processing, fruit/vegetable/fish drying, greenhousing, tourism etc.)?

8. Are there any policy, regulatory or institutional frameworks in place to promote gender mainstreaming in the geothermal sector? Are there any programs or initiatives (government, donor, private sector, NGO etc.) that specifically aim to increase the participation of women in the geothermal sector/provide opportunities for women entrepreneurs? E.g. specialized education initiatives, quotas requiring inclusive participation of women etc.

9. Do women have equal access to capacity building and training services (e.g. vocational training/technical education) or do they experience discrimination in access to these services?

The survey below was administered to various representatives from the local communities at the identified geothermal sites in each country. Feedback from these surveys was used to assess the commercial and technical viability of geothermal direct use projects for each community.

III. <u>OVERVIEW OF DIRECT USE APPLICATIONS:</u>

1. What are the agricultural activities in the area? Please list all that apply.

2. Are the agricultural activities for domestic consumption or commercial purposes?

3. What are the typical economic activities, occupations and sources of income for residents in the area? What is the typical monthly/annual household income?

4. Please describe the main demographic characteristics of residents in the area (age, gender, household size etc.)?

5. What are the potential geothermal direct uses in your community (select all that apply):

☐ Drying vegetables/fruits/tea leaves – please specify ....

☐ Aquaculture – please state the types of fish ....

☐ Fish drying

☐ Grain drying

☐ Greenhouse heating – please specify the crops ....

☐ Milk pasteurization

☐ Meat Processing

☐ Desalination of water

☐ Production of irrigation water

☐ Balneotherapy (hot springs/spa)

☐ Others (please specify) ....

6. From the selected technologies (response to #5), please provide estimated quantities of raw material crops produced (if applicable):

....

....

....

7. If the geothermal direct use projects/technologies listed above are implemented, what would be the expected impact on:

Marketing of the produce?

☐ No change

☐ Slight improvement in marketing (still limited to local area)

☐ Major improvement in marketing (extended beyond the local area)

Price of the commodity?

☐ No change

☐ Slight improvement in price (based largely on better preservation of produce)

☐ Major improvement in price (based on expanded business opportunity beyond the local area)

8. Is demand expected to increase when the above technologies are adopted?

   ☐ No change in demand

   ☐ Moderate increase in demand

   ☐ Large increase in demand

IV. SELECTED DIRECT USE APPLICATIONS:

4.1 FRUIT / VEGETABLE DRYING

1. What are the most common fruits and vegetables produced in the community?.........................

2. Estimate the number of fruit and vegetable farms within 100 km radius of the geothermal resource.........................
   How large are these farms on average (sq. km)?

3. Describe/estimate the levels of post and pre-harvest losses, as well as the main causes of these losses. What are the impacts associated with these losses?

4. Estimate the cost of transporting fresh fruits and vegetables to the geothermal resource.........................

5. What is the estimated cost of common fresh fruits (per Kg) .... cost of common fresh vegetables (per Kg) ....

6. Is there any existing fruit and vegetable drying station in the community that can potentially utilize the geothermal resource?

7. Is there demand for dry fruits and vegetables in your country (outside of your local community)? ......Yes / No.......
   If yes, please specify which types of fruits and vegetables: ....

8. What is the estimated level of consumption of dried fruits and vegetables for a typical household in your community (kg/month) ....

9. If possible/available, estimate the export demand for dry fruits/vegetables (kg/month) ....

10. Estimated price of dried fruits and vegetables (per Kg) .... include local and export market data (if available)

11. What are some of the key barriers / challenges associated with exporting dry fruits/vegetables?

4.2 FISH DRYING

1. What is the estimated cost of fresh fish (per Kg) ....

2. Estimated price of dry fish to be sold (per Kg) .... include local and export market data (if available)

3. Is there any water body with fishing activity within 100km radius of the geothermal resource?

4. Estimate the number of fishermen in the community .... Estimate the volume of fresh fish harvested by a typical fisherman (kg/month)?

5. Describe/estimate the levels of fishery losses, as well as the main causes of these losses. What are the impacts associated with these losses?

6. Estimate the cost of transporting fresh fish to the geothermal resource..........................

7. Is there any existing fish drying station in the community that can potentially utilize the geothermal resource?

8. Is there demand for dry fish in your country (outside of your local community)? ......Yes / No.......
   If yes, please specify which types of fish: ....

9. Estimate the level of demand/consumption of dry fish for a typical household in your community (kg/month) ....

10. If possible/available, estimate the export demand for dry fish (kg/month) ....

11. Estimated price of dried fish (per Kg) .... include local and export market data (if available)

12. What are some of the key barriers / challenges associated with exporting dry fish?

4.3 GRAIN (RICE) DRYING

1. What is the estimated cost of freshly harvested rice (per Kg)? ....

2. Estimate the number of rice plantations within 100 km radius of the geothermal resource..........................

3. How large are these plantations on average (sq. km)? What is the yield of a typical rice plantation per year (Kg)

4. Describe/estimate the levels of post and pre-harvest losses, as well as the main causes of these losses. What are the impacts associated with these losses?

5. What rice drying methods are currently being utilized in the community? What are the current costs of rice drying (per Kg)?

6. Estimate the cost of transporting freshly harvested rice from plantations to the geothermal resource......................

7. Is there any existing mechanical rice drying station in the community that can potentially utilize the geothermal resource?

8. Is there demand for rice in your country (outside of your local community)? ......Yes / No.......

9. Estimate the level of demand/consumption of rice for a typical household in your community (kg/month) ....

10. If possible/available, estimate the export demand for rice (kg/month) ....

11. Estimated price of dry rice to be sold (per Kg) .... include local and export market data (if available)

12. What are some of the key barriers / challenges associated with exporting rice?

4.4 <u>TEA DRYING</u>

1. What is the estimated cost of fresh harvested tea leaves (per Kg) ....

2. Estimate the number of tea leaf farms within 100km radius of the geothermal resource .... How large are these farms on average (sq. km)?

3. Is there any existing tea factory in the community that can potentially utilize the geothermal resource?

4. What is the estimated cost of transporting fresh tea leaves to existing tea processing facilities (per Kg)...................

5. What is the estimated price of processed tea (per Kg) .... include local and export market data (if available)

6. What is the estimated level of local consumption of locally processed tea per household (tea bags/week) ....

7. Is there export demand for processed tea? Estimated export demand for processed tea (kg/month) .... (if available)

8. What are some of the key barriers / challenges associated with exporting tea?

4.5 <u>GREENHOUSES</u>

1. What are the typical flowers grown outdoors in the region?..........................

2. What are the typical fruits, vegetables and flowers grown in greenhouses in the region?..........................

3. Is there particular demand for greenhouse produce over outdoor produce in your local community and in your country in general? ....Y/N.............. Are households willing to pay more for greenhouse produce?

4. Is there any existing greenhouse in the area that can potentially utilize the geothermal resource? How big is this existing greenhouse?

5. What is the estimated level of demand for a typical household in the community for the different types of greenhouse produce (kg/month) ....

6. What is the estimated level of export demand for the different types of greenhouse produce (kg/month) .... (if available)

7. What are the estimated selling prices of typical greenhouse crops (per Kg) .... include local and export market data (if available)

8. Estimate / provide the cost of acquiring land in the region for setting up a greenhouse.

4.6 MILK PASTEURIZATION

1. What is the estimated cost of raw milk (per liter) .... Include data for large scale commercial diary producers and small holder producers (if available)

2. Estimate the number of farms producing raw milk within 100km radius of the geothermal resource........................
   How many of these are large scale commercial dairy producers and small holder producers? How big are the large scale and small scale farms respectively on the average?

3. Estimate the cost of transporting raw milk to existing milk processing facilities (per liter)..........................

4. Is there any existing milk processing facility in the area that can potentially utilize the geothermal resource?

5. Estimate the price of pasteurized milk (per liter) .... include local and export market data (if available)

6. Estimate the level of local consumption of locally pasteurized milk per household (liters/month) ....

7. Is there export demand for pasteurized milk? Estimated export demand for pasteurized milk (liters/month) .... (if available)

9. What are some of the key barriers / challenges associated with exporting pasteurized milk?

4.7 BALNEOTHERAPY (HOT SPRINGS)

1. What activities do households in the community engage in for leisure during weekends and holidays?

2. How much can households in the community comfortably afford to spend for relaxation in a month or year?

3. What are the existing tourism products (sites) and estimated number of tour companies in the district? Amounts tourists are charged at these sites.

4. Estimate the number of tourist visits to the area annually.

5. Are there any existing hotels/resorts in the area that can potentially utilize hot springs?

6. Is the area easily accessible for tourists by a good network of roads?

7. What is the level of local awareness of the benefits of warm bathing and balneology?

8. Availability of essential infrastructures such as banks, hospitals, telecommunication coverage etc. in the area.

9. How far is the geothermal resource from the main city with airport?

10. Estimate / provide the cost of acquiring land in the region for setting up a spa.

4.8 SOCIAL AND GENDER QUESTIONS

1. Please describe the typical social structure/hierarchy within a typical household. Are households predominantly run by men or women?

   ☐ Men

   ☐ Women

   ☐ Both genders equally

2. Please describe the role of gender with regards to land ownership. Do men and women have equal access and opportunity to own land?

3. Please describe the role of gender with regards to access to credit. Do men and women have equal access to credit? Please specify whether this is from a financial institution and/or from informal sources of financing.

4. Are men or women typically more heavily engaged in agricultural / farming activities?

   ☐ Men

   ☐ Women

   ☐ Both genders equally

5. What kind of economic activities do women engage in and what women-led activities can be supported by geothermal direct use solutions? Please check all that apply.

   ☐ Agriculture (food processing, fruit/vegetable drying)

   ☐ Aquaculture and fish drying

   ☐ Greenhousing

   ☐ Tourism (balneotherapy)

   ☐ Other (please specify)

6. What mechanisms or approaches are in place (if any) to raise community awareness about direct-use geothermal applications and their potential benefits? Are community meetings held on a regular basis and do women also participate in these meetings?

7. Are there any related programs or initiatives (government, donor, private sector, NGO etc.) that specifically aim to build the capacity/develop the skills of women in these areas (e.g. food processing, fruit/vegetable/fish drying, greenhousing, tourism etc.)?

8. Are there any policy, regulatory or institutional frameworks in place to promote gender mainstreaming in the geothermal sector? Are there any programs or initiatives (government, donor, private sector, NGO etc.) that specifically aim to increase the participation of women in the geothermal sector/provide opportunities for women entrepreneurs? E.g. specialized education initiatives, quotas requiring inclusive participation of women etc.

9. Do women have equal access to capacity building and training services (e.g. vocational training/technical education) or do they experience discrimination in access to these services?

ANNEX 2: METHODOLOGY FOR GEOTHERMAL DIRECT USE PROJECT CATEGORIZATION

A summary of the approach and methods used to categorize the direct use (DU) projects identified in each community in **Section IV** of this report is presented below, including the data sources used and any assumptions that were made where first-hand information was unavailable.

The methodology below includes a scoring system to categorize potential DU applications in each of the identified communities. Specific DU applications were assigned to each site based on the potential for the associated geothermal resource to provide benefits to the local community. Different DU applications fit different geothermal sites.

1. What geothermal direct use applications can be considered for East African countries?

The space of DU applications is very wide depending to a large extent on the sustainable temperature of the available reservoir. While drying fruits and vegetables can be achieved with 50-60°C, drying timber is not feasible below 150°C. Given the limited scope of this study and in some cases due to a lack of available data, several assumptions were made regarding the quality of the geothermal resources. **It is important to emphasize that this is only a pre-feasibility study and is intended to provide a baseline for future research/full feasibility studies** (which will provide more reliable data based on actual drilling results).

The following assumptions were made:

- The resource temperature will be between 50-100°C. This is the temperature of the process, which means that we expect a resource temperature that is on average 20°C higher. Our initial analysis indicates that the majority of the investigated resources are on the lower end of the temperature scale.
- The other element one needs to account for when designing a specific DU application based on the geothermal resource is the sustainable flow rate to support continuous operation. For the sake of this study, we will provide only qualitative observations – meaning that there is no limit on the level of flow rate. During subsequent/full feasibility studies, when quantitative analysis will be called for, the specific resources will be evaluated based on actual flow rate (based on testing results).
- During this study, we will not analyze other elements associated with the suitability of the geothermal resources such as the quality of the geothermal brine, optimization of the geothermal field etc. All of these and other parameters will be analyzed once a full feasibility study is undertaken. At this stage, we will assume ideal conditions at the geothermal resource.
- Consequently, we will consider only those DU applications which do not require high temperature and are suitable in East Africa. We will therefore not consider timber or concrete drying as these are high temperature applications. Nor will we consider district heating, which is typically not applicable to most East African countries.
- And finally, we will consider only field proven technologies. There are plenty of good ideas (e.g. using geothermal heat for air conditioning, freezing of produce etc.)

2. Scoring System

A scoring system was developed to categorize some qualitative-based measures in assessing suitable DU applications for each site. This analysis should be a starting point for more granular studies (as part of full feasibility studies). A more detailed economic analysis of these applications will be provided in the subsequent phase of this assignment.

2.1 **Complexity of technology and associated levels of risk:** Some DU applications have been perfected over the years and are easy to install and operate, while others are more complex.

- For example, greenhouses for flowers require a basic piping system to run through the greenhouse. The heating impact is achieved usually via fans moving the air over the piping system. The system is quite simple to install and operate. Most importantly, any failure of the system would not result in catastrophe: some flowers may not reach maturity as quickly, but the loss would be minimal. Hence – **risk is low**. Other examples include getting drinking water or irrigation. In this case, we have no interest in the embedded heat (in fact, we work hard to cool the water as quickly as we can). And spas are also not too complicated to build and operate if the local conditions merit it.
- The other side of this spectrum involves sophisticated DU systems such as milk pasteurization, which is a much more complex system to construct and operate and needs to be operated in a fail-safe mode. Any failure can be disastrous and may cause not only financial loss, but may also result in health issues – Hence, **risk is high**. Other complex systems with DU applications such as air conditioning using geothermal heat, and other processes requiring sterilization.
- Somewhat **medium risk** (with respect to the selected technology) may be assigned to the areas of fruits, vegetable and fish drying. The systems can be rather simple (e.g. involving trays of the product inside a heated cabin or possibly the use of conveyers to accelerate the operation). Fish drying is inherently more complex as the fish needs to be processed quickly in order to avoid loss and potential health hazards. In the case of vegetables and fruits, there is always the alternative to use solar energy to dry the product, which is the current approach used in many African countries.

2.2 **Community or individual:** Some DU applications can be developed by individuals as they do not require major investments or large labor efforts. Some technologies (milk pasteurization as an example) require the whole community to commit. Generally speaking, the commercial prospects of successful DU applications improve the bigger the plant and greater level of community buy-in/commitment.

2.3 **Economic considerations and impact:** The aim is to promote projects which make sense economically but that can also have a larger development impact on the community. This not only means increasing the income of the affected communities, but also the ability to provide high paying jobs to the youth, develop local skills, productive use applications etc.

2.4 **Physical constraints:** As the project is planned on a special site, we need to consider the distance from the geothermal resource, the infrastructure needed to develop the project etc. If the source of the fish is too far from the resource, it may not make sense to build a fish drying plant as a DU project.

2.5 **Other considerations:** Under this section, we point to different factors which may impact the priority of DU applications for specific resources. For instance, many communities were enamored with the idea of balneotherapy. It can attract tourists from the country and abroad. A self-flowing thermal spring can be used to fill in a spa. But the truth is that most successful spas in the world use the brine from operating geothermal plants which are used mainly for power generation.

3. Preliminary Recommendations for DU Project Categorization at the Identified Sites

The table below corresponds to the analysis presented in **Section IV** of this report. Here we are providing our preliminary recommendations as to the suitable resources in the order of which DU applications should be prioritized. A next step would involve a full feasibility study of these potential applications at each of the identified communities/sites.

Geothermal Site	Categorized DU Applications	Description
DJIBOUTI		
Ambado PK-20	1. Vegetable/fruit drying	The survey indicates no immediate good use of the geothermal resource. Agriculture seems possible as no fishing or other industries around which may benefit from the use of geothermal heat.
Asal Fiale	1. Vegetable/fruit drying 2. Fish drying 3. Balneotherapy	This community will benefit from the facilities to dry vegetables and fruits and may give a boost to a nascent fishing industry. As to balneotherapy, the community is already attracting tourists and an additional attraction may be useful.
Hanle Garabbayis	1. Vegetable/fruit drying 2. Balneotherapy	This community does not seem to be in a dire need for DU application based on the nearby geothermal resource. Some agriculture can benefit from the ability to dry the product in a more efficient way. There is also the potential for construction of a spa for recreation/tourism.
ETHIOPIA		
Aluto-Laugano	1. Fish drying 2. Greenhouse 3. Balneotherapy	Fishing seems to be a major industry in this region and drying the fish will certainly bring about many economic benefits. There is already a sector of greenhouses in the area. Bringing geothermal heat to the current and new greenhouses will increase profitability and reduce pollution. And finally, the location of this community is suitable to consider balneotherapy/spas.
Dubti	1. Vegetable/fruit drying 2. Fish drying	There is already a recognition by the local community that these two sectors are the pillars of the local company and both can be improved operationally and economically by applying modern and environmentally friendly systems to dry the products.
Abaya	1. Grain drying 2. Fish drying	The demand is already there. And being on a lake, drying fish seems like a natural application of the local geothermal heat.
KENYA		
Olkaria	1. Water for irrigation 2. Fish drying 3. Chicken hatcheries	Presently the community is harvesting water for drinking and irrigation. This process is exceedingly time consuming and the need is very much there. The water coming from a DU application can be cooled further and delivered to the community. Fishing is a major industry because of the lake and drying the product will allow for an export industry. And finally, there is an increasing interest in providing heat to chicken factories and hatcheries.
Eburru	1. Water for domestic consumption 2. Pottery 3. Pyrethrum	The community here is also constrained by the supply of water for domestic consumption and irrigation, which means they stand to benefit from collecting the geothermal water in more efficient way to provide an immediate benefit to the community. Pyrethrum is currently being dried using solar energy. Automating the process will increase productivity and provide a short payback period.
Menengai	1. Water for agriculture 2. Vegetable/fruit drying 3. Greenhouse	The community in this area benefits from the ongoing activities in the Menengai geothermal field. Hence, the DU applications mentioned above do resonate with the community.

RWANDA		
Bugarama	1. Fish drying 2. Tea leaf drying	No information was available at the time of this study related to local demand and other parameters. This categorization therefore reflects our best estimate as to the DU applications which may be applicable to these sites and communities.
Gisenyi	1. Vegetable drying 2. Fish drying	Information related to demand and other parameters was somewhat limited. This categorization therefore reflects our best estimate as to the DU applications which may be applicable to these sites and communities.
Karago	1. Vegetable drying 2. Milk pasteurization	While information related to demand and other parameters was limited, it seems that there is strong potential for a milk pasteurization facility at this site. It is reasonable to assume that the heating source for this operation is currently using fossil fuels; replacing this fuel source with heat from the geothermal resource will be beneficial economically as well for the environment.
TANZANIA		
Kiejo-Mbaka	1. Vegetable drying 2. Fish drying 3. Milk pasteurization	Thanks to the efforts of TGDC, the community in this area seems to be quite ready to embrace the concept of geothermal DU applications. While the benefit of drying agriculture products and fish is quite clear, it is recommended to review the installation of a milk processing facility. This of course requires a communal effort, but it seems that both the supply and demand exist.
UGANDA		
Kibiro	1. Vegetable and grain drying 2. Balneotherapy	Plenty of opportunities here to replace solar drying systems with more efficient geothermal DU heat. This is true for vegetables as well as grains. In addition, this area seems well suited to many tourists; with the infrastructure in place, constructing a spa could be beneficial.
Buranga	1. Fish drying 2. Tea leaf drying 3. Balneotherapy	Fishing is the local industry and drying the product will significantly increase the market opportunities. In addition, drying tea leaves can assist in the supply chain of this product by saving time in processing. And finally, this site attracts many tourists annually, so a spa may be beneficial.
Panyimur	1. Vegetable/fruit drying 2. Tea leaf drying 3. Rice drying 4. Fish drying	This community seems to be blessed with many agriculture products and is also able to use the nearby lake for fishing. It seems that it is ready for the next step in implementing the most efficient DU applications.

Source: Community surveys; GreenMax Capital Advisors analysis

APPENDIX: ANALYTIC FRAMEWORK FOR SITE SELECTION

The analytic framework is enclosed in a separate file.

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