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The African Networks of Centres of Excellence on Water Sciences Phase II (ACE WATER 2)

Status of Geothermal Industry in East African Countries

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Cover image: Well testing at Menengai geothermal field, Rift Valley, Kenya (photo by Alfredo Battistelli)

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Executive summary

The present activity has been performed within the project "The African Networks of Centres of Excellence on Water Sciences PHASE II (ACE WATER 2)", that aims at fostering sustainable capacity development at scientific, technical and institutional level in the water sector, being implemented in partnership between UNESCO and the JRC.

In this framework, the analysis of energy production and demand patterns has a major relevance for the assessment of both current socio-economic conditions and future developments. Among others, the role of hydropower is expected to further expand in the near future in most African countries, accounting for a major impact in terms of electricity production, but also posing various social, technical and scientific challenges. Among them, the medium-long term sustainability, face to impact of climate variability and climate change on water availability, the competing water use among the different economic sectors and human water supply needs, and the potential conflicts due to water allocation policies, particularly in transboundary basins.

Hydropower has been the object of specific scientific analysis in a WEFE (Water-Energy-Food-Ecosystem) nexus perspective at few of the major continental river basins, namely:

- the Zambezi river basin, by promoting scientific collaboration among the region CoEs, experts in hydrology and hydropower from the Un. of Rhodes and the Un. of Florida, and the JRC, addressing the basin development priorities as identified by ZAMCOM;
- the Blue Nile, through the active collaboration of key CoEs in the region, namely the Un. of Khartoum/Sudan and the AAU/Ethiopia, addressing the challenges of future envisaged developments (e.g. the GERD).

Although not explicitly addressed, the topic of energy and hydropower production also play a major role in other major basins, that have been investigated in the framework of the project, namely the Lake Victoria and the Niger river basins.

In the light of the debate on energy production and on renewable energy in Africa, a decision was finally taken to integrate the overall framework by investigating the role and potential of geothermal energy, that looks like promising in several countries along the East African Rift System (EARS), geographically extending from Eastern to Southern Africa.

The general objective of the report is to present the state-of-the-art on the geothermal resource development in East African Countries (Eritrea, Djibouti, Ethiopia, Kenya, Uganda, Rwanda, Burundi, Tanzania and Comoros) and in two Southern African countries (Malawi and Zambia), for the sake of simplicity all collectively referred to as "East African countries".

The focus of the report is on geothermal activities aimed at generating electric power by using either flashing or Organic Rankine Cycle (ORC) plants with geothermal fluids extracted from medium to high temperature hydrothermal systems. A summary of the present status of geothermal development initiatives underway in each of the 11 countries is given, distinguishing between: surface exploration projects; drilling exploration projects; well field development and power plant design and construction projects; exploited geothermal fields.

The business models implemented are discussed, in relation with the peculiar features of the geothermal energy which is characterized by important initial investments and limited operating and maintenance expenditures, as most of the renewable energy sources, but having peculiar remarkable mining risks mainly related to the exploration drilling phase.

Constraints delaying a more widespread use of geothermal energy for electric power generation in East Africa are analysed together with the role of international and financial institutions in providing funds and risk mitigation opportunities, support in capacity building and the development of national legal frameworks needed for an improved and faster development of geothermal resources in East Africa.

The report is the result of a desk-based work, consisted in a literature review of selected papers and news approximately from year 2005, searched on web resources and dealing with geothermal resources development in East African countries. The review includes published papers, reports and documents that are available through the World Wide Web (WWW).

While any reasonable effort has been assured to collect the relevant information, of course the literature review cannot be complete and exhaustive because of the so many projects underway and so many international and national stakeholders acting in the 11 African countries considered. In addition, while most of the general information is available to the public through the WWW, the details on specific initiatives are often not readily available and, on the other hand, the published information is not always updated.

Geothermal energy: a low environmental impact renewable energy

Geothermal resources, consisting in the heat contained in the Earth crust, are presently exploited for both electric power generation and for direct uses. Apart for the utilization of low temperature resources (<100°C) only made for direct uses, the generation of electric energy is made from medium (between 100°C and 200°C) and high (>200°) temperature geothermal systems.

Favourable geodynamic environments allow founding exploitable geothermal systems at economic and technical feasible depths, generally not exceeding 4,000 m. Almost all the high temperature geothermal fields exploited today are hydrothermal systems from which heat is extracted by means of wells producing fluids contained in a permeable reservoir. According to thermodynamic conditions, the reservoir can be either vapour or liquid dominated depending on the fluid phase controlling the reservoir pressure distribution. Extracted geothermal fluids are used to operate condensing turbines or ORC plants, depending on their thermodynamic conditions. Geothermal power plants typically are used to supply the base load as field exploitation is performed following the natural well production decline with minimal well regulation. Thus, geothermal energy supplies almost constant power with a load factor often in the order of 90% and more, independent on weather conditions and seasons.

Full reinjection of separated brines and recovered condensed steam is customarily performed to avoid environmental pollution, to recharge the exploited reservoir and to avoid subsidence effects. Lifecycle greenhouse gas emissions of geothermal power generation are typically lower than that of fossil fuels power generation, and comparable to those of solar PV, biopower and concentrated solar power.

The larger flash or direct steam plants allows to achieve lower levelized cost of electricity generation (LCOE) than the smaller ORC plants. Well managed geothermal field developments allow a LCOE lower than about 0.07-0.08 USD/kWh, which is competitive with electricity generated with fossil fuels. Geothermal energy is also an indigenous energy source less prone to the instability of international O&G market.

Phases of geothermal resources development

Even today, different countries and agencies employ different methodologies and techniques in developing a project to utilize a geothermal resource. The IGA (2014) guide for geothermal exploration divides the process of developing geothermal projects into eight key phases, in line with the ESMAP Geothermal Handbook (Gehringer and Loksha, 2012), as follows:

I. Preliminary survey
II. Exploration
III. Test drilling
IV. Project review and planning
V. Field development

VI. Power plant construction

VII. Commissioning

VIII. Operation

According to Gehringer and Loksha (2012), it may take approximately seven years (usually between 5 and 10 years) to develop a typical full-size geothermal project with a 50 MW turbine as the first field development step. Of course, the project development time may vary depending on the relevant country's geological conditions, information available about the resource, institutional and regulatory framework, access to suitable financing, and other factors. Due to this long project execution cycle, geothermal power is not a quick fix for any country's power supply problems, but rather should be part of a long-term electricity generation strategy.

Each of the above phases of geothermal project development consists of several tasks. After each milestone, the developer, either a private company or a country's institution, must decide whether to continue developing the project or not. The first three phases take the developer from early reconnaissance steps to field exploration and to test drillings. This first part of the project development (which could be broadly called the exploration stage) either confirms the existence of a geothermal reservoir suitable for power generation or not: it is usually seen as the riskiest part of project development. A strong reduction of the risk is obtained only after the positive results of the test drilling phase, that is the confirmation of the existence of the geothermal reservoir by drilling and testing of exploration wells, but this phase is much more expensive than the previous surface exploration phase, by more than one order of magnitude.

Once the existence of an exploitable geothermal reservoir has been confirmed, its main characteristics evaluated through drilling and well testing results, and the technical and economic feasibility positively evaluated, the field development phase and the power construction phase can be performed, pending the availability of related funding resources.

Thus, the development of a geothermal resource for power generation is characterised by: a long execution period with distinct phases and milestones to be fulfilled; the presence of mining risks related to the early exploration drilling phase which are similar to those afforded by the O&G industry; the availability of high skilled technical resources in several disciplines including geosciences, drilling and reservoir engineering, plant engineering and project management; the requirement of experienced drilling contractors and specialised service companies; finally the high initial costs for field development and power plant EPC which are recovered during a long term operation period with low maintenance and operation costs, which make geothermal energy similar to the power industry.

Geothermal projects development in East Africa

Historically, reconnaissance and preliminary surface studies on geothermal prospects in East Africa where performed by public institutions or companies supported by international donors and consultants. In a few cases this approach allowed also to drill the first exploratory wells, like in Olkaria (Kenya), Aluto and Tendaho (Ethiopia), and Asal (Djibouti). Often, this approach has been characterized by a discontinuous performance of exploration phases separated by long periods of inactivity, sometime accompanied by the switch of operations from one institution to another one, with loss of skilled personnel and know-how. More recently most of the countries have developed regulatory environments in which both public and private operators, as well as private-public initiatives are allowed to develop the geothermal resources.

The example of Kenya, with an institutional setup of its energy sector similar to that of the most advanced geothermal countries in the World, testifies that the opening to private investors and operators, as well as to the collaboration between public companies in charge of the exploration and field management and Independent Power Producers, allows an accelerated and more effective development. Other countries are following Kenya in establishing a clear regulatory environment and accelerating the initial prospects exploration with dedicated public companies.

Recognized obstacles to the development of geothermal resources utilization in East Africa

While the East African Rift System geodynamic context creates high favourable conditions for the existence of geothermal systems at economically and technically drillable depths, with a global potential estimated at 15,000 - 20,000 MW, at present only Kenya has developed its geothermal resources with an installed electric power of about 865 MW, against estimated resources from 7,000 MW up to 10,000 MW (Omenda, 2018b). Despite exploration drilling performed since the 80's in both Djibouti and Ethiopia, no power generation is at present active in both countries.

There are several reasons for the delay of geothermal resources development experienced so far by East African countries, such as:

- the lack of clear and coherent legislative frameworks regulating the activities of both public and private investors in several countries.
- the lack of local technical and managerial skills able to conveniently support the exploration and exploitation of geothermal resources.
- the remoteness of many East Africa geothermal areas from developed O&G regions where most of the drilling contractors and service providers are based, and then the absence of infrastructures and logistic facilities supporting the drilling activities characterising well developed O&G regions.
- inadequate financing of the early stages of geothermal projects; commercial banks reluctance to participate in the exploration phase and the need for more risk reduction opportunities which facilitate the investment by both public and private operators.
- competition from other energy sources, such as Hydro in Ethiopia and several other countries, which creates a challenging environment for geothermal projects in the region.
- the issue of remunerative price for the generated electric power in still poor developed national electric markets.

In order to help East African countries to overcome the above issues, international organizations and financial institutions are actively collaborating with national governments to create the necessary legislative framework in each country. They have facilitated the capacity building with the organization of dedicated courses and conferences and the creation of the Africa Geothermal Centre of Excellence (AGCE) in Kenya, taking advantage of the existing training facilities of GDC and KenGen.

Geothermal power plant development involves substantial capital requirements due to exploration drilling costs, for which it can be difficult to obtain bank loans. Since geothermal exploration is considered high risk, developers generally need to obtain some type of public financing. This risk is derived from the fact that capital is required before confirmation of resource presence or exploitability, and therefore before project profitability can be determined.

Some of the Governments (Kenya, Uganda, Tanzania) have decided to reduce this risk and the cost of capital for private developers by creating public companies in charge of initial exploration activities and in some case also to exploit geothermal resources and provide private companies (that install power plants and supply electricity to their customers) with the required steam.

An important risk mitigation opportunity is represented by the Geothermal Risk Mitigation Facility for Eastern Africa (GRMF) which is providing grants covering a variable costs fraction for infrastructure construction, surface exploration surveys and exploration drilling, that are the phases characterized by the higher mining risks. After 5 Application Rounds, grants have already been awarded to 30 projects located in Djibouti, Ethiopia, Kenia, Uganda, Tanzania and Comoros. The expression of interest for the 6th Application round has started on May 6, 2020.

Finally, several international stakeholders are actively supporting all the phases of geothermal field development, from exploration to power plant EPC, with grants and soft loans and providing technical assistance and consultant support to national institutions and geothermal operators.

While the role of international institutions has been fundamental in supporting the geothermal exploration and development in East Africa countries in the last decades, sometime the support given was limited to a specific phase after which no further support was available, determining strong delays in the performance of further phases. Often the same prospect has been explored and developed with funding coming in different times from different institutions, very often with different consultants that had to review each time the data and results of previous activities. This approach was not always effective, and produced changes in strategy, unnecessary reiteration of reviews and processing of data, and consequently delays in the development process and higher costs.

The Eastern Africa Rift System (EARS)

Geothermal systems, which can be at present economically and technically exploited at depth generally not exceeding 4,000 m, are found in peculiar geologic and geodynamic environments which are strictly linked to plate tectonic features enhancing locally the heat transmission from the mantle towards the Earth crust. The EARS, an intracontinental rift, is one of such geodynamic environments. It is the continental branch of the worldwide mid ocean rift system that corresponds to the third arm of the Afar- Red Sea – Gulf of Aden triple junction. The EARS splits into an Eastern and a Western branch at about 5°N. The Eastern Branch comprises the Afar depression at the North and the Ethiopian, Turkana and Kenya Rift Valleys to the South, till the North of Tanzania. The Western Branch starts in Uganda to the North end, and comprises Albert, Kivu, Tanganyika, Rukwa and Malawi Rift Valleys. Its SW extension comprises Luangwa-Kariba-Okavango rifts in Zambia.

The Eastern Branch is characterized by a much widespread quaternary volcanic activity, with large calderas and volcanic centres along the rift axis, with the presence of shallow magma bodies. Geothermal prospects are mainly consisting in volcanic hosted high temperature geothermal systems. The Western Branch has limited volcanic centres, with the absence of shallow magmatic bodies and is characterized by geothermal prospects mainly associated to medium, rarely high, temperature fault controlled hydrothermal systems. While the overall EARS geothermal potential is estimated at more than 15,000 MW, the eastern Branch is for sure characterized by a higher potential mainly concentrated in the Afar depression (Djibouti and Ethiopia) and the Ethiopian and Kenyan Rift valleys.

The role of geothermal energy in the energy mix of the East Africa countries depends on the present status of the energy markets of each country, on the potential of indigenous energy sources, including geothermal energy, and strategic choices taken by each government. The East Africa countries have all some common features such as: a rapidly increasing population whose majority still lives in the country side mainly occupied in subsistence agriculture; low annual per capita income countries, with plans to become in a near future middle income countries; the majority of energy consumption still satisfied by Biomass (wood and charcoal) with adverse impact on the ecosystems; low per capita electric energy consumption with the majority of population still not reached by electric national networks; high fraction of electric energy generated by Hydro resources (with the exception of Eritrea, Djibouti and the Comoros), high potential for development of Solar PV and Wind resources, low use of O&G for electric power generation (with the exception of Eritrea, Djibouti, Tanzania and the Comoros); plans to consistently increase the installed electric power, extend the national electric networks and focus on renewable indigenous energy sources.

Eastern Branch

Looking at the present situation in each country, it appears evident that the countries crossed by the Eastern Branch of EARS have a definitely higher geothermal potential, mainly concentrated in the Afar depression and the Ethiopian and Kenyan Rift Valleys. Even if not huge on an absolute scale, the resources inferred in Eritrea, Djibouti and the Comoros (the latter not actually pertaining to the Eastern Branch of EARS), if developed, would contribute to a large fraction of their present and future electric network base load.

Exploration of Alid volcanic complex in **Eritrea** shall be completed in order to allow the location and drilling of exploratory wells. The inferred Alid prospect potential of 70 MW would cover a large fraction of the country base load, as the total installed power capacity amounts at some 195 MW.

The extensive reconnaissance and surface surveys performed in **Djibouti**, supported by exploration drilling at Asal Rift and North Ghoubet have not yet identified geothermal resources suitable for industrial development, being pending the results of recently drilled wells at Fialé caldera prospect in the Asal Rift where a potential of up to 50 MW was inferred. A 50 MW geothermal development would represent a significant fraction of country base load, as the total installed power is at present about 123 MW.

Surface exploration of the Karthala geothermal prospect in Grande Mayotte, **Comoros**, allowed to identify a geothermal potential of up to 40 MW, largely exceeding the base load of the country, where the installed potential amounts at present at 22 MW, of which 16 MW are installed in Grande Mayotte. Exploration wells have been targeted and a project is underway with the aim to drill 3 exploration wells.

Ethiopia has a large geothermal potential estimated at some 10,000 MW in the most optimistic evaluations, which at present is still untapped after more than 40 years of surface surveys over more than 20 prospects and deep exploratory wells drilled at Aluto caldera and at the Tendaho graben. The situation seems to be ready to evolve thanks to the award of 8 exploration licenses to international experienced operators and 3 drilling projects managed by the Ethiopian Electric Power company at Aluto caldera, and Dubti and Alalobad prospects within the Tendaho graben. Tulu Moye Geothermal Operation is ready to start exploration drilling at the Tulu Moye prospect, while Corbetti Geothermal Plc will soon start the exploration drilling at the Corbetti caldera which might be the greater geothermal field in Ethiopia. Other important prospects are under exploration at Abaya, Fentale, Boku, Shashemene, Duguno and Dofan for both high and medium temperature geothermal reservoirs.

The promulgation of geothermal proclamations in 2016 and 2019 has definitely clarified the regulatory framework for the development and use of geothermal resources in Ethiopia, with clear procedures for the award of licenses for reconnaissance, exploration, and development and use of geothermal resources for electric power generation by both private and public operators. The competition of geothermal energy with other renewables in Ethiopia, and particularly with massive Hydropower resources, is for sure problematic, but the willing of the Government of Ethiopia to definitely develop its geothermal resources seems to be proven by the recently signing of updated Power Purchase Agreements with Tulu Moye Geothermal Operation and Corbetti Geothermal Plc. The direct involvement of experienced international operators should definitely allow the construction and operation of geothermal plants in Ethiopia. For those prospects directly explored by the Ethiopian Electric Power Co., the subsequent building and operation of the power plants by Independent Power Producers might be a suitable option, in particular for the Dubti and Alalobad prospects in the Tendaho graben.

Kenya is the leading country in Africa as far as the development and exploitation of geothermal resources is concerned, with 865.4 MW installed at the end of 2019, of which 706.8 MW are operated by KenGen at the Greater Olkaria field, where other 155 MW are operated by OrPower 4 Inc. Geothermal energy is now the primary source of electric energy in the country.

The development of the Greater Olkaria Field is a success story witnessing the capabilities acquired by KenGen in all the different phases of resource development, from surface exploration and deep drilling to plant construction and field exploitation. Geothermal Development Company (GDC) is the national company in charge of the development of geothermal resources in Kenya. Both KenGen and GDC have their own drilling rigs and are capable to execute integrated drilling services both in Kenya and in surrounding countries.

The Kenyan geothermal energy sector has a well-defined institutional set-up which foreseen the role of both public and private companies in the exploration activities as well as on building and operating geothermal plants. Different Public Private Partnerships models are allowed, making the Kenya market close to the most advanced geothermal markets in the World. Geothermal power development is projected to increase by 328 MW between 2020 and 2022 with the commissioning of Olkaria PPP (140 MW), Olkaria 1 Unit 6 (83.3 MW) and Menengai (105 MW).

In addition to further development of the Greater Olkaria field by KenGen and OrPower 4 and the development by GDC of Menengai, GDC already performed exploration drilling at Paka and is planning exploration drilling at Suswa, Korosi and Silali prospects. Private operators are active on other prospects such as Olsuswa Energy Ltd at Barrier prospect, Africa Geothermal International Ltd al Longonot prospect, Capital Power Ltd at Homa Hills prospect, Arus Energy Ltd at Arus prospect, Akiira Geothermal Ltd at Akiira prospect. Other prospects that include Lake Baringo, Elementaita, Namarunu, Emuruangogolak, and Lake Magadi, licensed to GDC and private developers, are still in the planning stages.

Tanzania is interested by both the southern end of the Eastern Branch and by the Western Branch of the EARS. The Government of Tanzania has invested considerably on its geothermal resources by creating a dedicated company, TGDC, for the development of geothermal resources with special focus on four flagship projects for a short-term target of 200 MW. Surface exploration activities performed on the 3 of the above 4 prospects, namely Kiejo-Mbaka, Songwe and Luhoi, suggested medium temperature reservoirs in the range of 110-150°C suitable for direct uses and power generation using ORC plants. Surface exploration of Ngozi prospect inferred a potential of at least 30 MW (P50) related to a high temperature reservoir beneath the Ngozi crater, with an ongoing exploration drilling project. At present, the surface exploration results suggest that the short-term target of 200 MW is far to be realized with the 4 flagship prospects initially considered by TGDC. The sites with known thermal manifestations on the Western Branch of the EARS suggest low to medium temperature geothermal systems likely to be fault controlled. Different perspectives could be liked to geothermal areas located in the Northern province belonging to the Western Branch of the EARS, such as Natron prospect for which a surface exploration study has been planned by TGDC. The overall picture of present geothermal development in Tanzania suggest that the potential is probably much lower than in Ethiopia and Kenya. In addition, this limited potential should compete with the large Hydro and natural gas resources on which the present generation of electric energy is mostly based.

Western Branch

The geological settings and the exploration activities performed so far suggest clearly that the countries crossed by the Western Branch of EARS have a lower geothermal potential, mostly related to medium, rarely high, temperature fault controlled geothermal systems whose utilisation for electric power generation would require ORC power plants.

Uganda is located at the northern end of the Western Branch of EARS which crosses the country on its western border. So far, four potential areas located in the Western Branch of the EARS have been identified and studied with detailed surface exploration surveys and drilling of gradient wells, namely Katwe-Kikorongo, Buranga, Kibiro and Panyimur. Results achieved so far suggest medium temperature fault-controlled reservoirs with temperatures in the range 110 – 150°C, with possible upper temperature of 200°C for the Buranga prospect only. These temperatures would require the use of ORC plants for power generation. All the four prospects are not yet ready for deep exploratory drilling. Despite the optimistic evaluation of Uganda geothermal potential, amounting up to 1,500 MW, at present the results of detailed exploration performed on the 4 most promising prospects are indicating that geothermal resources suitable for power generation are still to be confirmed.

Despite the willing and efforts of the Government of Uganda to utilize the geothermal resources of the country, results achieved so far do not allow to hypothesize that geothermal energy will be soon available to contribute to the base load of the national electric network. It seems also that even if exploration will be finally successful, geothermal energy will not be able to give a remarkable contribution to the future electric energy generation in Uganda, which will be probably dominated by Hydro with the contribution of other renewables.

Rwanda is located along the Western Branch of EARS and is crossed NS on its western part by the Rift Valley. Despite its position, the geothermal potential of Rwanda, initially estimated in the range 170-340 MW, has been recently revised down to 90 MW within the 2015 Electricity Master Plan. This in principle would still be an interesting potential in a country in which the present installed power amounts to some 220 MW. Exploration activities have been conducted on four most promising prospects, namely Karisimbi, Kinigi, Gisenyi and Bugarama. Two of them resulted not to host a geothermal system, namely Karismbi where two deep exploratory wells failed to find interesting temperature, and Kinigi. Surface exploration concluded also that Buragama is a typical low-temperature system, with temperature in the range 75-115°C, not suitable for power generation. Higher temperatures up to about 160-200°C have been inferred for a deep reservoir in Giseny, but additional surface exploration was deemed necessary before moving to the deep exploration drilling phase.

Despite the willing of the Government of Rwanda to diversify the sources of electric energy generation by developing also geothermal resources, results achieved so far indicate that the known geothermal sites in the country have an overall limited potential and will not be able to give a remarkable contribution to the future electric energy generation in Rwanda, unless improved exploration approaches targeted to fault controlled systems will be able to identify new promising prospects.

Burundi is located along the Western Branch of EARS and is crossed NS by the Rift Valley. Geochemical surveys suggest the highest temperatures should be found in the Rusizi Valley, with an inferred geothermal resource with temperature in the range of 100°-160°C. The reconnaissance activities performed so far confirm that hydrothermal geothermal resources of low and medium temperature might exist in Burundi, but the actual characteristics of those resources still need to be confirmed with surface exploration studies on most promising sites. Geothermal energy could contribute to the Government of Burundi plans to increase and diversify the sources of electric energy generation by providing a stable fraction of base load, but those resources are reasonably expected to be limited.

Malawi is located at the SW end of the Western Branch of EARS along the Rift Valley. The reconnaissance and surface exploration activities performed so far confirm that hydrothermal geothermal resources of low and medium temperature exist in Malawi. A Geothermal Exploration Project encompassing the whole country completed in 2018 identified Chiweta and Kasitu as the most promising prospects with inferred temperature between 110° and 135°C, at the lower temperature range for electric power generation with ORC plants, with an estimated potential of some 10 MW each. According to the results of the project, a limited contribution from geothermal resources to the country energy requirements can be reasonably expected.

Zambia is located at the extreme SW end of the Western Branch of EARS. The strategy of ZESCO, the public utility in charge of geothermal development, has identified five priority prospects on which detailed surface studies need to be completed, namely Chongo and Kapisya in the North, Lubungu and Mupiamanzi in the West, Chinyunyu in the East, even though preliminary investigations suggest that Kapisya and Chinyunyu prospects have low potential for power generation. More advanced surface exploration surveys supported by the drilling of gradient wells have been performed by Kalahari GeoEnergy at Bweengwa River prospect in southern Zambia. Results confirm the existence of a fault-controlled geothermal system with temperatures up to 150°C that can support a power generation project of at least 10 MW based on ORC plants. Kalahari GeoEnergy is extending the exploration to Kafue Trough where a resource with characteristics similar to the Bweengwa River prospect are expected.

The reconnaissance and exploration activities performed so far confirm that hydrothermal geothermal resources of low and medium temperature exist in Zambia, mainly linked to fractured bed rocks and fault-controlled systems. A total potential for some 50 MW to be generated using ORC plant is inferred. Despite the Government of Zambia need and willing to diversify the sources of electric energy generation, it seems that even in the most optimistic case geothermal energy will be able to supply only a very small fraction (<1.5%) of electric power planned from renewable sources.

Foreword

The present activity has been performed within the project: "The African Networks of Centres of Excellence on Water Sciences PHASE II (ACE WATER 2)", that aims at fostering sustainable capacity development at scientific, technical and institutional level in the water sector. The project supports twenty AU-NEPAD African Network of Centres of Excellence in Water Sciences and Technology (CoEs) organized in three regional networks, in conducting high-end scientific research on water and related sectors, in order to provide effective scientific and educational support to governments. The project is implemented in partnership between UNESCO, in charge of the human capacity development component, and the JRC that coordinates the scientific component and leads the project.

In the framework of the project scientific component, the Southern and Central-Eastern Africa Networks of WATer Centers of Excellence respectively identified the Zambezi river basin and two relevant sub-catchments (Blue Nile Basin and the Lake Victoria Basin) of the Nile river basin as common study areas for the development of common research undertakings.

These basins pose many challenges from a perspective of Water-Energy-Food-Ecosystem (WEFE) nexus, including among others: hydropower, reservoir multipurpose optimization and release management, coupled surface water and groundwater management, rain-fed and irrigated agriculture development, impact of land use and agricultural practices (including livestock and fisheries), role of ecosystem services (natural parks, wetlands), pressures on resources due to population growth, climate change, climate variability and extreme events risks (drought and flooding).

In the framework of the energy component of the WEFE nexus, analysis has been focused up to now on hydropower, playing a major role in most of the study areas, with relevant planned future developments and key challenges on transboundary water availability, as is the case for the assessment of impacts of the GERD (Great Ethiopian Renaissance Dam).

Although of minor relevance, still the geothermal energy production potential looks like promising in few countries, along the East African Rift System (EARS), geographically extending from Eastern to Southern Africa. Hence the envisaged need to provide a state-of-the-art review of the topic, whose subject is better detailed here below.

Subject

The general objective of the present report is to frame the state-of-the-art on the geothermal resource development in East African Countries (Eritrea, Djibouti, Ethiopia, Kenya, Uganda, Rwanda, Burundi, Tanzania and Comoros) and two Southern African countries (Malawi and Zambia). For the sake of simplicity, all the above countries will be collectively referred to as "East African countries".

The focus of the report is on geothermal activities aimed at generating electric power by using either flashing or Organic Rankine Cycle (ORC) plants. The results of the research allow to draft a summary of the present status of geothermal development initiatives underway in each Country, distinguishing between: surface exploration projects; drilling exploration projects; well field development and power plant design and construction projects; exploited geothermal fields.

The business models implemented are discussed, in relation with the peculiar features of the geothermal energy which is characterized by important initial investments and limited operating and maintenance expenditures, as most of the renewable energy sources, but having peculiar remarkable mining risks mainly related to the exploration drilling phase.

Constraints delaying a more widespread use of geothermal energy for electric power generation in East Africa are analysed together with the role of international and financial institutions in providing funds and risk mitigation opportunities, support in capacity building and the development of national legal frameworks needed for an improved and faster development of geothermal resources in East Africa.

1 Introduction

Geothermal energy is a renewable energy characterized by: low environmental impact and greenhouse emissions when compared to energy generated using fossil fuels; quite constant generation output independent from weather conditions, which makes it particularly suitable for base load electric generation; high initial capital costs and low operating and management expenditures; remarkable mining risks mainly related to the performance of exploratory drilling phase.

While well developed in Iceland, Italy, Turkey, USA, Mexico, New Zealand, in Far East (the Philippines, Indonesia, Japan) and Central America Countries (Costa Rica, El Salvador, Nicaragua), geothermal resources are at present only marginally exploited in Africa, with the exception of Kenya, despite favourable geodynamic conditions in East Africa.

East Africa is characterized by the presence of the East African Rift System (EARS) with: the Eastern branch extending from Eritrea to Tanzania and crossing Djibouti, Ethiopia and Kenya; the Western branch extending from Uganda to Mozambique and crossing Burundi, Rwanda, Zambia, Tanzania, Malawi. While this geodynamic context creates high favourable conditions for the existence of geothermal resources at economically and technically drillable depths, at present only Kenya has developed its geothermal resources with an installed electric power of about 700 MW, against estimated resources amounting to some 7,000 MW. Despite exploration drilling performed since the 80's in both Djibouti and Ethiopia, no power generation is at present active in both countries.

The general objective of the present report is to frame the state-of-the-art on the geothermal resource development in East African Countries with the focus on geothermal activities aimed at generating electric power by using either flashing or Organic Rankine Cycle (ORC) plants (DiPippo, 2012; Moon and Zarrouk, 2012). The development stage of geothermal sector in East Africa countries is quite variable, depending on the potential and characteristics of their inferred geothermal resources, the local energy market, and existing economic and legislative frameworks.

The report is divided in three main sections:

- Introduction: which briefly introduces the main characteristics of geothermal energy, gives an overview of the geothermal resources in the East African countries, discuss about the phases of geothermal resources development and summarizes the main obstacles to the development of geothermal industry in East Africa.
- International Stakeholders: which present the main international institutions active in funding geothermal projects, providing technical assistance to local Governments and organizing technology transfer and capacity building to local Governments and companies.
- Countries Status: drafting a summary of the present status of geothermal development initiatives underway in each Country, distinguishing between: surface exploration projects; drilling exploration projects; well field development and power plant design and construction projects; exploited geothermal fields.

Finally, a References section lists all the references cited within the text.

The report is the result of a desk-based work, consisted in a literature review of selected papers and news approximately from the year 2005, searched on web resources and dealing with geothermal resources development in East African countries. The review includes published and unpublished documents that are available through the worldwide web.

While any reasonable effort has been assured to collect the relevant information within the time constraint of the present study (from March 13 to May 15, 2020), of course the literature review cannot be complete and exhaustive because of the so many projects underway and so many international and national stakeholders acting in the 11 considered countries.

In addition, while most of the general information is available to the public through the WWW, the details on specific initiatives are often not readily available and, on the other hand, the published information is not always updated.

The World Geothermal Congress (WGC) 2020 was scheduled in Reykjavik from March 27 to April 1, 2020. Papers presented at the WGC are an important source of updated info and data. In particular, the geothermal countries update is usually presented giving the state of the art of exploration and exploitation activities in each country. WGC 2020 has been postponed to May 21-26, 2021, because of COVID-19 health crisis. But papers were already submitted and are available at https://www.geothermal-energy.org/explore/our-databases/conference-paper-database/ and https://pangea.stanford.edu/.

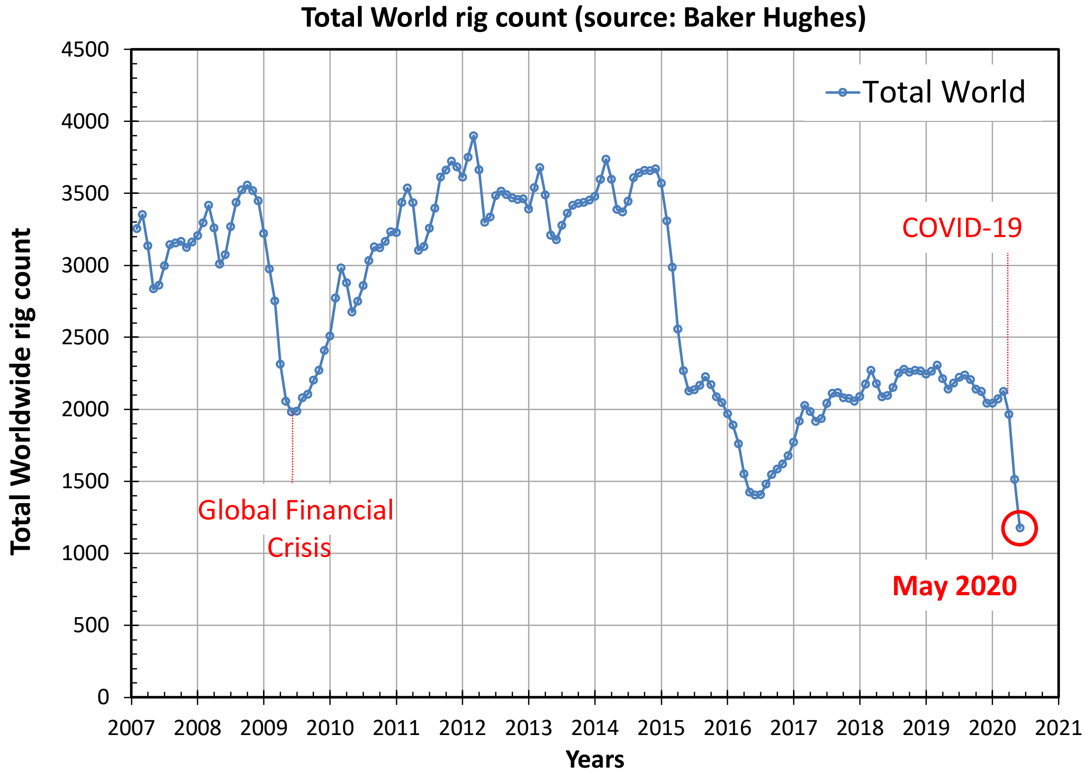
Activities related to this report began on mid-March 2020, just a few days after a complete lockdown was enforced in Italy due to the COVID-19 pandemic. Italy was followed shortly by most of European countries and by the United States. The lockdown enforced, even with different approaches, has already heavily affected the economy and the energy market at a global scale. IEA (2020) estimates that as a consequence of the efforts to slow the spread of the virus, the share of energy use that was exposed to containment measures jumped from 5% in mid-March to 50% in mid-April. IEA analysis of daily data through mid-April shows that countries in full lockdown are experiencing an average 25% decline in energy demand per week and countries in partial lockdown an average 18% decline, while global energy demand declined by 3.8% in the first quarter of 2020. Renewables (Solar PV and Wind) are the only source that showed a growth in demand, driven by larger installed capacity and priority dispatch.

The present analysis of geothermal industry in East Africa countries and in particular of planned future developments, is based on available documentation which does not account at all the effects of COVID-19 pandemic on the global economy and the energy consumption in 2020 and on the years to come. Those effects might have an impact on the energy planning of East Africa countries. Moreover, the major global supply chain disruptions are of course having an impact on on-going projects which relay on goods and services also supplied by international companies. The prediction of the future effects of COVID-19 pandemic on the development of geothermal resources in East Africa countries is outside of the scopes of the present analysis.

A few considerations can be any way made with respect to the effects on geothermal industry activities:

- the slowdown of energy consumption affects heavily the fossil fuels demand with a strong consumption decline and in a less amount the electric energy consumption;
- electric power generation will be cheaper using fossil fuels, but geothermal energy investments are decided looking to power plant operations in the order of at least 25-30 years. Thus, decisions are not taken looking at short term crude oil price changes;
- the crisis affecting the O&G industry is strongly affecting the drilling operations as proven by the April and May 2020 decline of the number of drilling rigs active worldwide shown in **Figure *1***.
- this slowdown of O&G drilling market will make drilling operation on geothermal fields cheaper, as the same drilling contractors, service companies and consumable materials of the O&G industry are employed.

Figure 1. Total World rig count (Source: Baker-Hugues https://rigcount.bakerhughes.com/intl-rig-count)



1.1 Geothermal energy: a low environmental impact renewable energy

Geothermal resources, consisting in the heat contained in the Earth crust, are presently exploited for both electric power generation and for direct uses. Apart for the utilization of low temperature resources (<100°C) only made for direct uses, the generation of electric energy is made from medium (between 100°C and 200°C) and high (>200°) temperature geothermal systems.

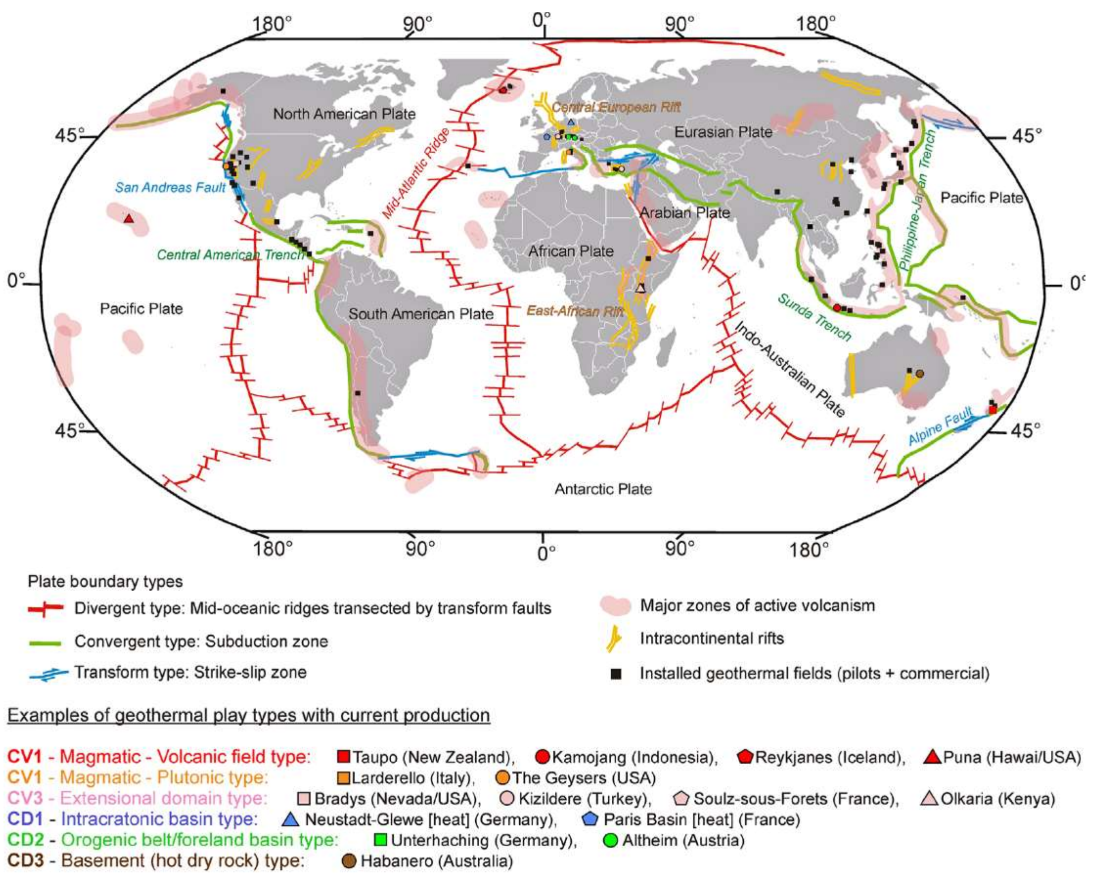
The USGS definition of a geothermal system (Williams et al., 2011) is as follows: "*A geothermal system is any localized geologic setting where portions of the Earth's thermal energy may be extracted from a circulating fluid and transported to a point of use. A geothermal system includes fundamental elements and processes, such as fluid and heat sources, fluid flow pathways, and a caprock or seal, which are necessary for the formation of a geothermal resource*."

Geothermal systems which can be at present economically and technically exploited at depth generally not exceeding 4,000 m, are found in peculiar geologic and geodynamic environments which are strictly linked to plate tectonic features enhancing locally the heat transmission from the mantle towards the Earth crust. **Figure 2** (USGS, 1997) shows the relationship between the boundary of tectonic plates and volcanic activity, while Figure 3/3 shows the correlation between the location of major geothermal plays (both pilot and commercial) and plate tectonics.

Figure 3 clearly shows as most of geothermal plays are located in volcanic areas corresponding to mid-oceanic ridges, subduction zones, strike-slip zones, and intracontinental rifts.

Figure 2. Plate tectonics and active volcanoes (Source: USGS, 1997)

Figure 3. Plate tectonics and location of exploited (pilot + commercial) geothermal fields (Source: IRENA, 2014)



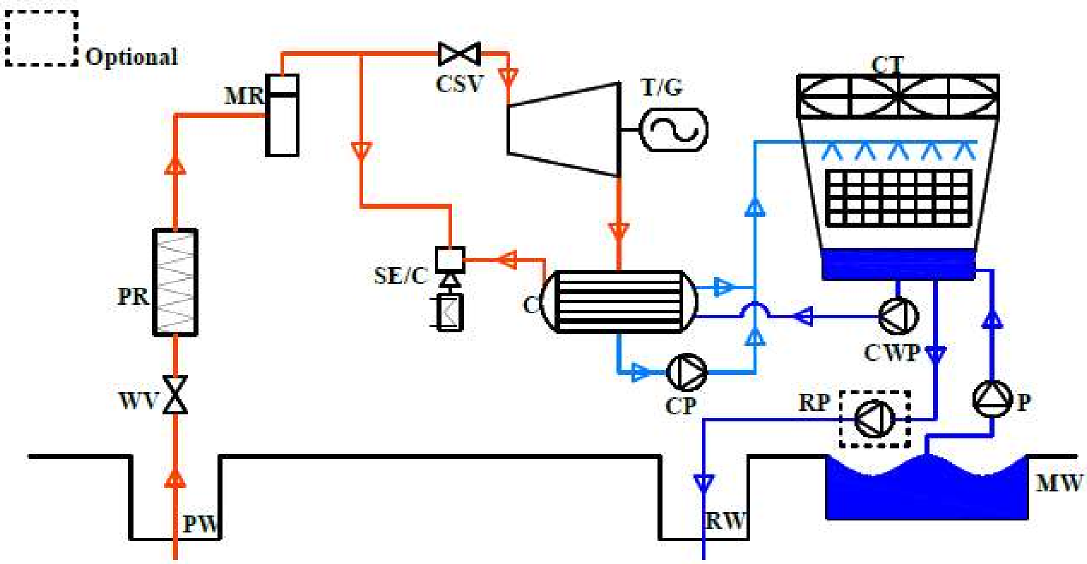
Favourable geodynamic environments allow founding exploitable geothermal systems at economic and technical feasible depths. Almost all the high temperature geothermal systems exploited today are hydrothermal systems from which heat is extracted by means of wells producing fluids contained in a permeable reservoir. According to thermodynamic conditions, the reservoir can be either vapour or liquid dominated depending on the fluid phase controlling the reservoir pressure distribution.

Vapor dominated reservoirs produce dry steam, either saturated or superheated, which is piped to a condensing power plant, whose simplified scheme is shown in

Figure 4 (Moon and Zarrouk, 2012). The condensed steam recovered at the condenser (typically 25-30%) is pumped to reinjection wells, while the non-condensable gases (NCG) are extracted from the condenser and discharged to the atmosphere after possible treatment for the presence of contaminants (H_2S, Hg). A rarely used alternative to a condensing turbine is a backpressure turbine where the steam and NCG at turbine outlet are directly discharged to the atmosphere. The gathering system (also known as Fluid Collection and Reinjection System, FCRS) includes the steam pipelines from production wells to the power plant and the reinjection lines for the recovered condensed steam. Vapor dominated fields are not common. Examples are The Geysers (USA), Larderello (Italy), Kamojang, Darajat and Patuha (Indonesia), Matsukawa (Japan).

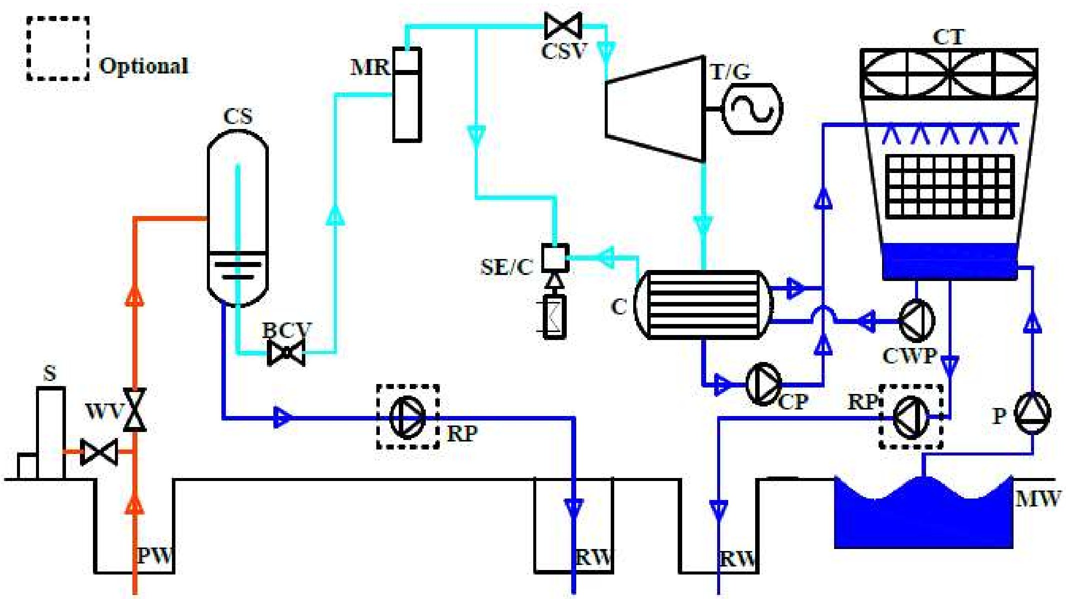
Liquid dominated high temperature reservoirs produce a two-phase mixture of steam and brine, which is separated and piped through steam and brine pipelines to a single-flash condensing power plant, whose simplified scheme is shown in **Figure 5** (Moon and Zarrouk, 2012). The separated brine and the condensed steam recovered at the condenser are piped to reinjection wells, while the NCG are extracted from the condenser and discharged to the atmosphere. Possible alternative to a single-flash condensing turbine is a double-flash plant where the separated brine undergoes a second flash at a lower pressure to feed a low-pressure stage of the turbine. The gathering system includes the steam pipelines from separation stations to the power plant, the brine reinjection lines from the separation stations to the reinjection wells and the reinjection lines for the recovered condensed steam. Liquid dominated reservoirs are the most common high temperature geothermal fields presently exploited. Two-phase conditions may be present within the reservoir under the natural state as a steam-cap or can evolve during exploitation as a consequence of reservoir pressure depletion and in-situ boiling of liquid phase.

Figure 4. Simplified schematic of a dry steam plant (Source: Moon and Zarrouk, 2012)



PW	Production well	WV	Wellhead valve	PR	Particulate remover
MR	Moisture remover	C	condenser	CP	Condensate pump
CSV	Control and stop valve	SE/C	Steam ejector/condenser	T/G	Turbine and generator
CT	Cooling tower	CWP	Cooling water pump	RP	Reinjection pump
RW	Reinjection well	P	Pump	MW	Make-up water

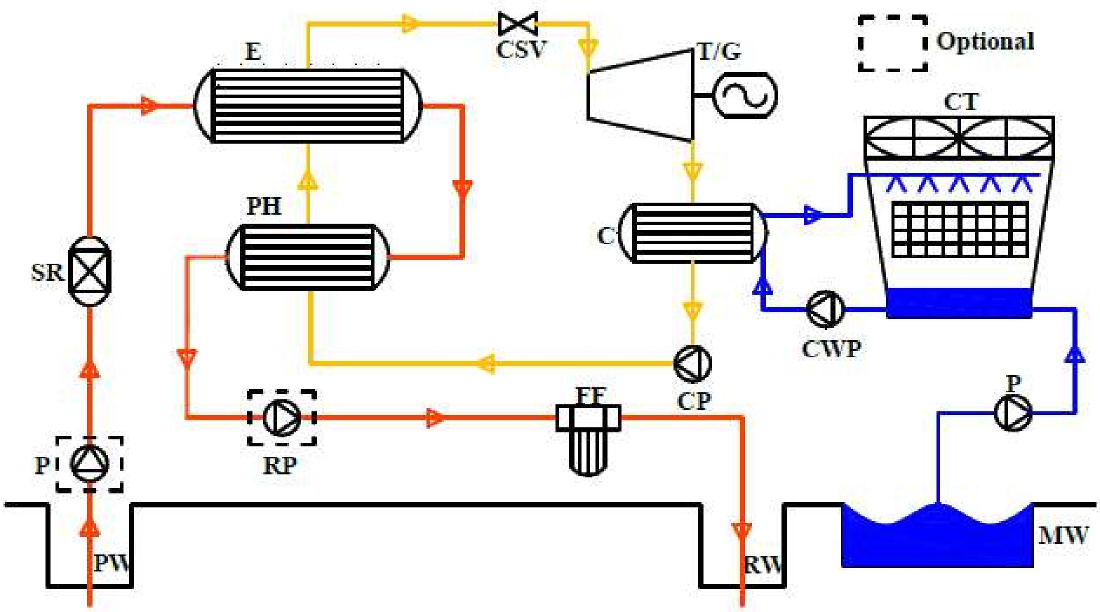
Figure 5. Simplified schematic of a single-flash plant (Source: Moon and Zarrouk, 2012)



PW	Production well	WV	Wellhead valve	S	Silencer
CS	Cyclone separator	BCV	Ball check valve	MR	Moisture remover
CSV	Control / stop valve	T/G	Turbine / generator	SE/C	Steam ejector/condenser
C	condenser	CT	Cooling tower	CWP	Cooling water pump
CP	Condensate pump	RP	Reinjection pump	RW	Reinjection well
P	Pump	MW	Make-up water		

Liquid dominated medium temperature reservoirs may produce liquid brine at wellhead, in particular when production is assisted with downhole pumps. The brine is piped to an Organic Rankine Cycle plant (ORC), also known as binary cycle plant as the heat carried by the brine is transferred to an organic fluid whose vapor feeds the turbine. The simplified scheme of an ORC plant is shown in **Figure 6** (Moon and Zarrouk, 2012). The hot brine is piped to the heat exchanger at the power plant, while the cooled brine is piped to reinjection wells. A possible alternative to the simple ORC plant fed by liquid brine only is that of an ORC plant fed by wells discharging a two-phase mixture of steam and brine. This happens often when the reservoir has a high content of NCG, like in all the Turkish fields located in the Menderes Graben, which promote gas lift and boiling within the producing wells. In this case separators at well pads are used and steam and brine are piped separately to the power plant, where two different heat exchangers are used for the steam and brine streams. The cooled brine and recovered steam condensate are piped to reinjection wells, while the NCG are discharged to the atmosphere. Thus, in this case the gathering system includes the pressure separators, the steam and brine pipelines from production wells to the power plant, the brine and condensate reinjection line from the power plant to the reinjection wells.

Figure 6. Simplified schematic of a basic ORC geothermal power plant (Source: Moon and Zarrouk, 2012)



PW	Production well	P	Pump	SR	Sand remover
E	Evaporator	PH	Pre-heater	C	Condenser
CP	Condensate pump	RP	Reinjection pump	FF	Final filter
CSV	Control / stop valve	T/G	Turbine / generator	CWP	Cooling water pump
CT	Cooling tower	RW	Reinjection well	MW	Make-up water

Independently from the reservoir type and power plant, the exploitation phase of a geothermal project requires three main components:

- Development of well field: drilling of production and reinjection wells required at plant start-up;
- Building of FCRS: separation stations, steam and brine pipelines and reinjection lines, with brine pumping stations where required;

- Building of power plant: main housing, turbines, generators, condensers, cooling towers, substations (plus heat exchangers in ORC plants).

Geothermal power plants typically are used to supply the base load as field exploitation is performed following the natural well production decline with minimal well regulation. Only in particular cases, like in geothermal plants feeding an isolated closed electric network on an island or in developed electric markets like in the USA, geothermal power plants are operated at variable load. Thus, geothermal energy supplies almost constant power with a load factor often in the order of 90% and more, independent on weather conditions and seasons.

The main advantages and downsides or challenges associated with geothermal power generation are summarized in **Table 1** as "pros" and "cons" (ESMAP, 2012).

Table 1. The Pros and Cons of Geothermal Power (ESMAP, 2012)

ADVANTAGE	DOWNSIDE/CHALLENGE
Globally inexhaustible (renewable)	Resource depletion can happen at individual reservoir level
Low/negligible emission of CO_2 and local air pollutants	Hydrogen sulfide (H_2S) and even CO_2 content is high in some reservoirs
Low requirement for land	Land or right-of-way issues may arise for access roads and transmission lines
No exposure to fuel price volatility or need to import fuel	Geothermal "fuel" is non-tradable and location-constrained
Stable base-load energy (no intermittency)	Limited ability of geothermal plant to follow load/respond to demand
Relatively low cost per kWh	High resource risk, high investment cost, and long project development cycle
Proven/mature technology	Geothermal steam fields require sophisticated maintenance
Scalable to utility size without taking up much land/space	Extensive drillings are required for a large geothermal plant

Among the major challenges of geothermal energy there are the high costs for field development and power plant EPC and the need to invest considerable funds before having the confirmation on the existence and characteristics of the geothermal resource (exploratory risks). The cost breakdown for two 110 MW plants in Indonesia is shown in **Figure 7**. Total drilling costs for exploration and field development amount to 24%, thanks to a relative competitive drilling market in Indonesia. Power plant and gathering system (steam field development) amount to 56%. The cost for infrastructures (access roads, well pads, base camps, water supply, etc.) amount to 7% of total cost.

In addition to specific field conditions, the final costs depend also on the power plant capacity and type. **Figure 8** shows the power plant cost per unit kWh installed for different power plant technologies (data for the 2007-2020 period). Generally, ORC plants characterized by smaller capacity have a higher installation cost than flash plants. This is due to both the scale economy which can be obtained with larger plants, but also to their lower conversion efficiency of thermal energy into electric power because of the exploitation of reservoirs with lower temperatures (VERKIS, 2013). On the other hand, ORC plants allow nowadays to generate electricity from liquid dominated reservoirs with temperature as low as 120°C, which is impossible with conventional flash plants (DiPippo, 2012).

Figure 7. Total installed Cost Breakdown for two proposed 110 MW geothermal plants in Indonesia (Source: IRENA, 2014)

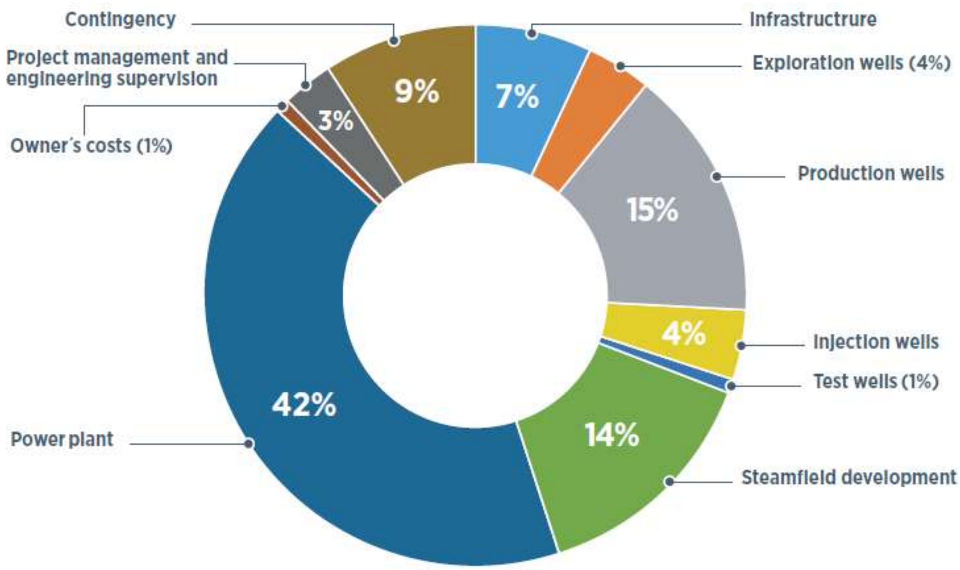
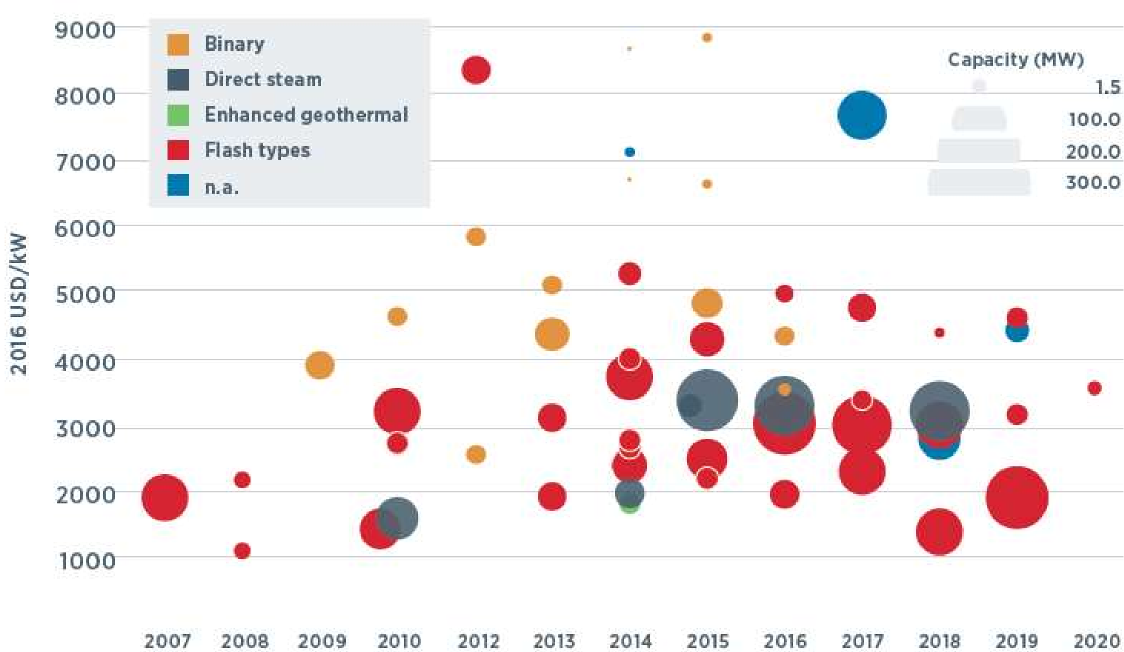


Figure 8. Geothermal power plant cost per unit kWh installed for different power plant technologies for the 2007-2020 period (Source: IRENA, 2017)



About the land requirements, it must be noted that often geothermal fields are in scenic volcanic areas which may be protected as natural parks. This for instance occurs often in Indonesia where geothermal fields are located along the volcanic belt in Sumatera, Java and Flores islands characterized by tropical forests, craters, calderas and volcanic lakes often protected by national parks. Something similar occurs in East Africa as geothermal areas in the EARS may be close or inside to national parcs protecting the wildlife.

The possible environmental impact of geothermal energy utilization (GEOLEC, 2013) slightly changes with respect to the type of geothermal facility, i.e. geothermal facility for exploiting high enthalpy hydrothermal resources, medium enthalpy hydrothermal resources and Enhanced Geothermal Systems (EGS), the latter being outside of the scope of the present report. The environmental impact of geothermal facilities may be divided into the following main categories:

- Surface disturbances, such as those caused during drilling, FCRS and plant construction, possibly affecting flora, fauna, surface water (access roads, pipe and power lines, plant and associated land use).
- Physical effects, like the effect of geothermal fluid withdrawal on natural manifestations, land subsidence, induced seismicity, visual effects (buildings, cooling towers, surface pipelines, power transmission lines etc.)
- Noise, such as equipment noise during drilling, construction and operation.
- Thermal pollution, such as due to hot water and steam release on the surface.
- Chemical pollution, like due to disposal of liquid and solid waste, gaseous emission to the atmosphere, natural radioactivity, etc.

The main activities causing environmental impact of geothermal facilities are:

- Building of access roads, drilling pads and pipelines for drilling water supply.
- Well drilling and well testing.
- Well workover.
- Laying of pipelines, electric power transformation and transmission lines.
- Plant construction and equipment installation.
- Power plant commissioning and operation.
- Decommissioning of facilities.

All the above impacts need to be properly evaluated by conducting Environmental and Social Impact Assessments (ESIAs), and subsequently monitored and mitigated with appropriate measures during all the phases of field exploration, development and exploitation

Special attention should be devoted to the emissions into the atmosphere of geothermal plants. This issue has two different aspects:

- The emissions of harmful NCG, such as H_2S and Radon, and of contaminants (Hg). This issue is at present one of the main concerns for the public acceptance of geothermal plants by local population in industrial countries.
- The level of GHG emissions of geothermal energy compared to other energy sources, which is becoming an issue to obtain funds from international financial institutions looking at the impact of funded projects on global warming.

Technologies for the abatement of H_2S and Hg from gaseous emissions in condensing power plants do already exist and are for instance applied on power plants operated by ENEL GreenPower in Italy. They could be in principle deployed in most of condensing power plants.

About greenhouse gas emissions linked to conventional geothermal power plants, the NCG extracted from the condenser are usually discharged to the atmosphere. Only in a few medium temperature fields producing liquid brine and exploited with ORC plants, the cooled brine with dissolved NCG is reinjected back into the reservoir. It is interesting to compare the Lifecycle average greenhouse gas emissions for different electricity generation technologies, expressed in terms of gCO_{2eq}/kWh (IPCC, 2011).

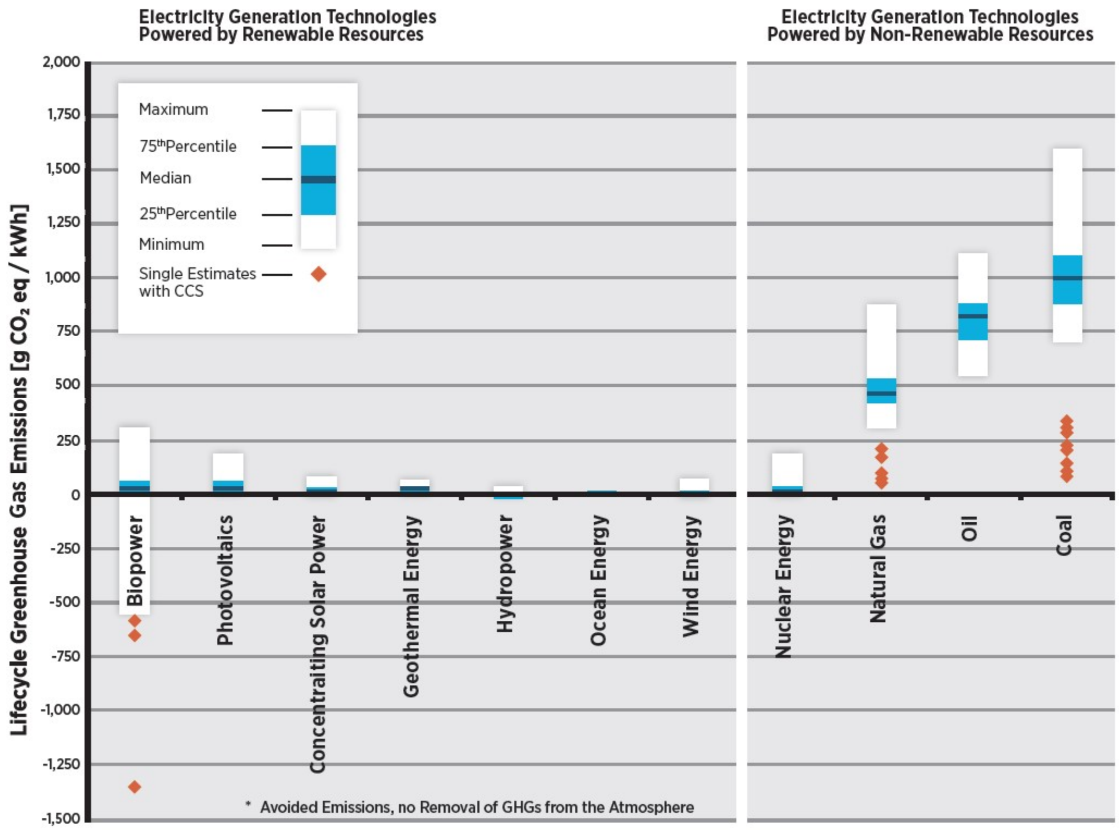
Figure 9 shows that, with respect to other renewables, emissions from geothermal power plants are higher than those of Hydropower and Ocean energy only, and lower than both Photovoltaic and Concentrating solar.

Despite the above encouraging figures, in the last years the reduction of GHG emissions from geothermal power plants became more and more important and it is now the subject of several R&D projects. Technologies under consideration mainly include: i) the capture of NCGs (more than 90% usually represented by CO_2) and their injection back into the reservoir or connected aquifers using dedicated pipelines and wells; ii) the co-injection of NCG with either separated brine and/or recovered condensed steam.

Even if the public acceptance of geothermal energy in East Africa still does not present particular issues, it is likely that funding institutions in a near future will require that new power plants will have GHG emissions below some predefined threshold.

In addition to environmental impacts also social impacts need to be addresses. International guidelines such as the IFC (2012a) Environmental and Social Performance Standards (PS1-PS8) are applied also to the planning and performance of geothermal projects, such as for labour and working conditions (IFC, 2012b), community health, safety and security (IFC, 2012c), land acquisition and involuntary settlement (IFC, 2012d), indigenous peoples (IFC, 2012e), and cultural heritage (IFC, 2012f).

Figure 9. Lifecycle greenhouse gas emissions for different electricity generation technologies (Source: IPCC, 2011)



	Biopower	Photovoltaics	Concentraiting Solar Power	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Nuclear Energy	Natural Gas	Oil	Coal
Count of Estimates	222(+4)	124	42	8	28	10	126	125	83(+7)	24	169(+12)
Count of References	52(+0)	26	13	6	11	5	49	32	36(+4)	10	50(+10)

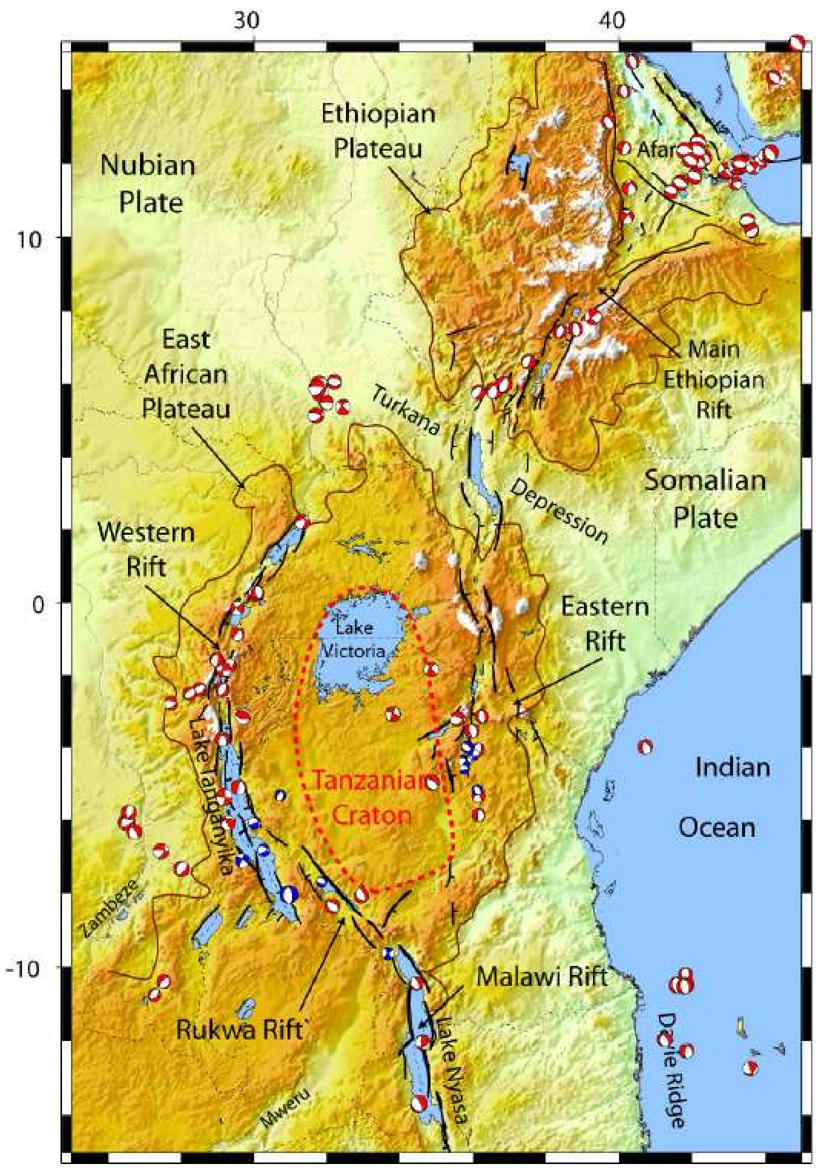
1.2 Overview of geothermal resources in East African Countries

Geothermal plays located in correspondence of intracontinental rifts are found in the East African Rift System (EARS). EARS is a succession of rift valleys that extend from Beira in Mozambique in the south to the Afar triangle (or depression) in the north (see

Figure 10), with a total distance of more than 4,000 km (Omenda, 2014; 2018b). The EARS is a continental branch of the worldwide mid ocean rift system that corresponds to the third arm of the Afar- Red Sea – Gulf of Aden triple junction. The rift is assumed to mark the incipient plate boundary between the Somali and Nubian micro-plates. The EARS splits into two at about 5°N to form the Eastern and Western branches. The Eastern Branch comprises the Afar depression and the Ethiopian, Turkana and Kenya Rift Valleys extending to the North of Tanzania, while the Western Branch comprises Albert, Kivu, Tanganyika, Rukwa and Malawi Rifts. Its SW extension comprises Luangwa-Kariba-Okavango rifts.

The volcanic and tectonic activity in the EARS started about 30 million years ago and in the Eastern Branch the activity involved faulting and eruption of large volumes of mafic and silicic lavas and pyroclastics. On the other hand, the Western Branch is characterized by paucity of volcanism, it is younger and dominated by faulting that has created deep basins currently filled with lakes and sediments.

Figure 10. The East African Rift System (Source: Omenda, 2018b)



Geothermal activity in the rift is manifested by the occurrences of Quaternary volcanoes, hot springs, fumaroles, boiling pools, hot and steaming grounds, geysers and sulphur deposits. The manifestations are abundant and stronger in the Eastern Branch that encompasses Afar, Ethiopian and Kenya rifts, where in the rift axis numerous central volcanoes of Quaternary age overlying products of Miocene and Pliocene volcanism occur. The shield volcanoes are built largely of intermediate lavas and by the associated pyroclastics, thus indicating the presence of shallow hot bodies (magma chambers) acting as heat sources of the geothermal systems. In the Afar rift where the crust is as thin as 5 km, extensive manifestations and high heat flux is due to a combination of mantle heat and magma bodies occurring at shallow depths.

Summarizing, the Eastern Branch is characterized by (Omenda, 2018b):

- Dominant basalt - trachyte – rhyolite volcanism;
- Large caldera systems in the axis of rift;

- Thick eruptive pile in the centre of Kenya and Ethiopian domes;
- Presence of shallow magma bodies;
- Dominant volcano hosted geothermal systems.

In the Western Branch, the surface manifestations activity is subdued and occurs largely as hot springs and fumaroles. It is characterized by paucity of volcanism along the entire length of the rift, with the main volcanic areas being Virunga and Rungwe. Heat sources are believed to be due to a combination of buried plutons and high heat flux associated with thinned crust.

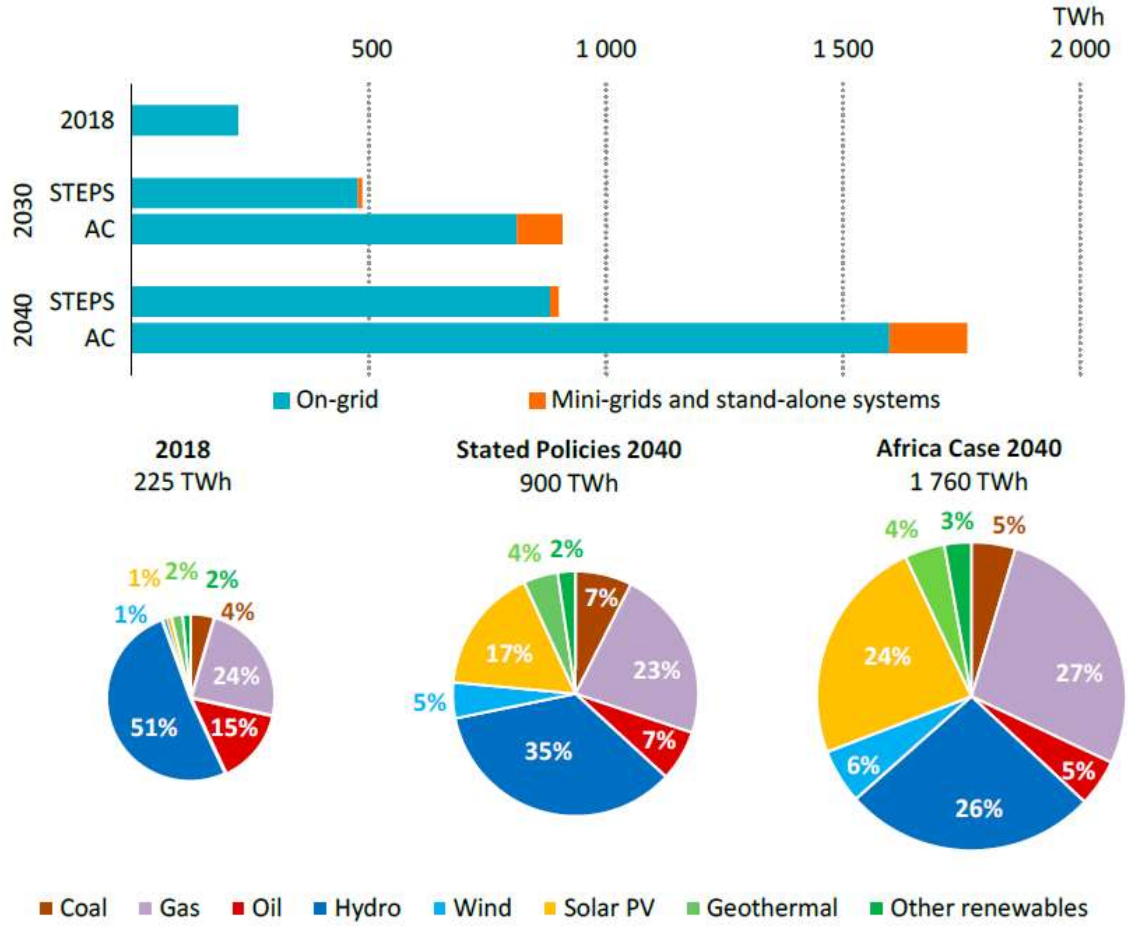
Summarizing, the Western Branch is characterized by (Omenda, 2018b):

- Dominant potassic alkaline volcanism;
- Absence of large caldera systems and volcanic centres;
- Thin lava pile;
- Absence of shallow magma bodies;
- Geothermal manifestations largely associated with fault systems;
- Dominant fault controlled geothermal systems.

Detailed and reconnaissance studies of geothermal potential in Eastern Africa indicate that the region has an overall potential from 15,000 MW (Omenda, 2014) to 20,000 MW (Omenda, 2018b). Resource potential estimates based on the results of reconnaissance and surface exploration studies, on which the above figures are mostly based, are customarily performed using the heat stored method, also known as volumetric method (Muffler and Cataldi, 1978). It is based on a static evaluation of heat in place, its recoverable fraction and the conversion of recoverable thermal energy into electric energy, neglecting all the hydrodynamic and thermodynamic processes that control the exploitation of a geothermal reservoir. It is obvious that such estimate is associated with extremely large margins of uncertainty, in particular with respect to the volume of the reservoir and to the recovery factor. Despite the uncertainties on basic parameters can be handled using the Monte Carlo approach, as suggested by Sarmiento and Steingrimsson (2007; 2011), the heat stored method historically proved to overestimate the actual resource potential (Grant, 2015). Thus, the above figures for the EARS geothermal potential shall be considered as upper values and used with caution.

It is also interesting to look at forecasted role of geothermal energy in the generation of electricity in sub-Saharan countries. **Figure 11** shows the electricity supply by type, source and scenario in sub-Saharan Africa, excluding South Africa (IEA, 2019a). The situation at 2018 is compared to two different scenarios (Stated Policies & Africa Case) at year 2040. The IEA's Stated Policies Scenario is based on current and announced policies, while the Africa Case scenario is a new scenario built by IEA around Africa's own vision for its future. It incorporates the policies needed to develop the continent's energy sector in a way that allows economies to grow strongly, sustainably and inclusively.

Figure 11. Electricity supply by type, source and scenario in sub-Saharan Africa (excluding South Africa), 2018 and 2040 (Source: IEA, 2019a)



In 2018 geothermal power accounted for 2% of electricity generation and is expected to represent in 2040 4% of electricity generation by both IEA's scenarios. Thus, geothermal is expected to double its contribution share in 2040, but still representing a small fraction of electricity generation, in particular if compared to the important increment of Solar PV which will compensate for the reduction of Hydro contribution. These scenarios both suggest that even if most of the investments on renewable energies will be drained by Solar PV, geothermal will anyway experience a large increment of generated energy and then of installed power.

1.3 Phases of geothermal resources development

Historically, many of the early geothermal projects were developed in a non-systematic manner. There were no clear guidelines or extensive experience to draw upon for the geothermal development process, while exploration was rudimentary at best. The first-time geothermal power was harnessed for electricity production was in Italy in the early part of the 20th century using shallow steam in the Larderello field (Tuscany region) from an area where surface discharges were clearly evident. In New Zealand in the 1950s, the developments of the Wairakei field, the first exploited water dominated filed, were initially justified by very high surface heat flows and the presence of numerous surface features, e.g., geysers and altered hot ground.

Developing an understanding and defining the stages or phases of how to develop a project to utilize a geothermal resource has taken time for the geothermal sector to accomplish. Even today, different countries and agencies employ different methodologies and techniques. The IGA (2014) guide for geothermal exploration divides the process of developing geothermal projects into eight key phases, in line with the ESMAP Geothermal Handbook (Gehringer and Loksha, 2012), as follows:

1. Preliminary survey
2. Exploration
3. Test drilling
4. Project review and planning
5. Field development
6. Power plant construction
7. Commissioning
8. Operation

According to the schedule in **Figure 12** (Gehringer and Loksha, 2012), it may take approximately seven years (typically between 5 and 10 years) to develop a typical full-size geothermal project with a 50 MW turbine as the first field development step. However, the project development time may vary, depending on the relevant country's geological conditions, information available about the resource, institutional and regulatory framework, access to suitable financing, and other factors. Due to this long project development cycle, geothermal power is not a quick fix for any country's power supply problems, but rather should be part of a long-term electricity generation strategy.

Each phase of geothermal project development consists of several tasks. After each milestone, the developer, either a project company or a country's institution, must decide whether to continue developing the project or not. The first three phases, or milestones, take the developer from early reconnaissance steps to field exploration and to test drillings. This first part of the project development (which could be broadly called the **exploration stage**) either confirms the existence of a geothermal reservoir suitable for power generation or not: it is usually seen as the riskiest part of project development. **Figure 13** shows the project cost and the risk profile of a typical geothermal project for a 50 MW power plant, as function of the 8 phases listed above (Gehringer and Loksha, 2012). A strong reduction of the risk is obtained only after the positive results of the test drilling phase, that is the confirmation of the existence of the geothermal reservoir by drilling and testing of exploration wells.

If the result from the first three phases, including the test drillings, is positive and the geothermal potential is confirmed, Phase 4 is initiated with the actual planning and design of the power project, including the feasibility study, engineering of components, and financial closure. Phases 5 to 7 comprise the development of the project itself, consisting of the drilling of geothermal production wells, construction of pipelines, construction of the power plant, and connection of the power plant to the grid.

Completion of each phase represents an increment in the developer's understanding of the geothermal system, a decrease in the overall uncertainty of the project's financial viability, a project decision point, and (usually) a requirement for significant financial investment.

Other consultants and developers may divide the process into a different number of phases (e.g., three phases: exploration, development, and operation; or five: reconnaissance exploration, pre-feasibility, feasibility, detailed design and construction, operation), but the underlying activities and philosophy are essentially the same.

While the 8 phases above cited are required to build and operate a geothermal power plant from scratch in a green field, usually they are not performed as a continuous flow of activities. More often phases such as reconnaissance, surface exploration, test drilling and field development are separated by time intervals of different length during which the operator (sometime different operators) is taking the necessary decisions, is looking for financing, and is applying for necessary licenses and permits. Often the reconnaissance phase is performed at a country or regional level on behalf of a state institution or agency. Promising areas are then selected for the performance of detailed surface exploration activities either by a state institution or agency, or directly by a public or private geothermal operator. The performance of surface exploration studies is usually subject to the award of an exploration license, a process which might take time in particular if licenses are awarded by the government on a competitive basis as happens in the most advanced geothermal markets (USA, The Philippines, Indonesia, Italy, Turkey, New Zealand, etc.).

The positive results of a surface exploration study allow to draw the prefeasibility study which delineates the prospect area to be investigated with deep exploration wells, locates the exploration wells, defines their basic design and the needs for infrastructures, and evaluates the overall costs of the exploration drilling phase. As the next step is characterized by an important investment, which may be in the order of 20-40 M USD for the drilling of 2-4 wells, and by a high mining risk, securing the necessary financing is usually challenging and might require considerable time.

Figure 12. Geothermal Project Development for a Unit of Approximately 50 MW (Source: Gehringer and Loksha, 2012)

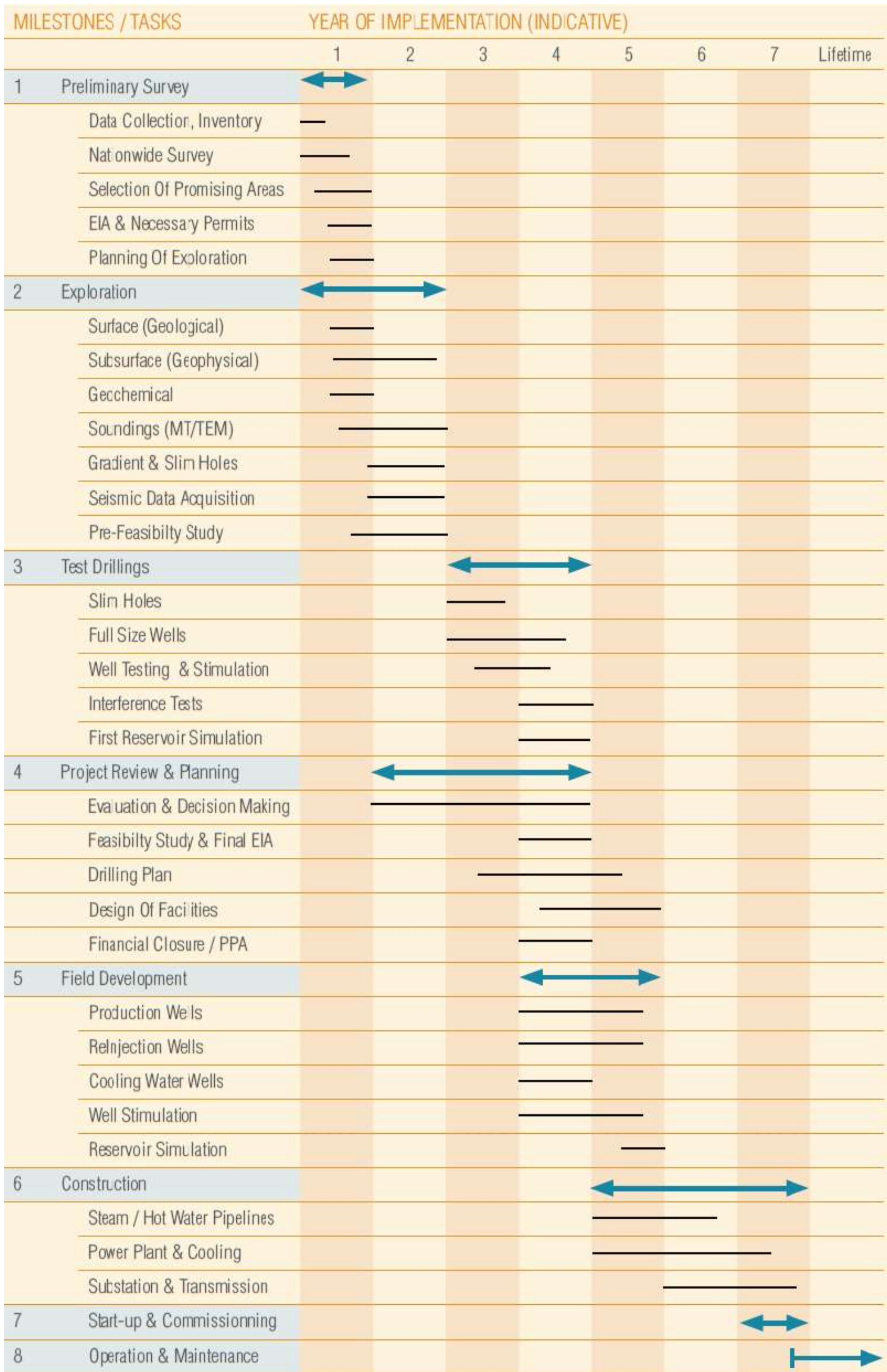
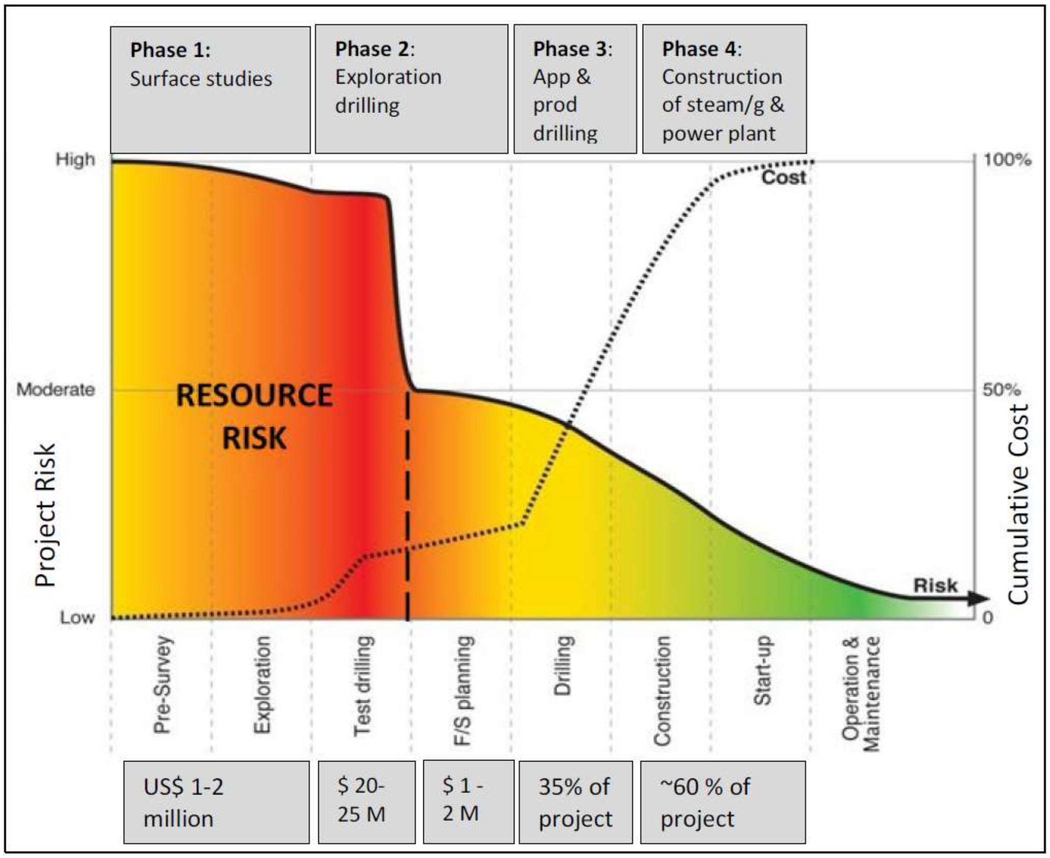


Figure 13. Project Cost and Risk Profile at Various Stages of Development (Source: Gehringer and Loksha, 2012)



Usually within the same project the drilling and testing of exploratory wells is followed by the evaluation of reservoir potential and by the execution of a feasibility study related to the field development and the installation of a power plant. The feasibility study is then used to find the necessary funds for the subsequent phases of field development (drilling of production and reinjection wells necessary at plant start-up), and of steam gathering system and power plant detailed engineering, procurement and construction (EPC). Depending on the Country regulations, the development phase might require the switch from the exploration license to a field development and use license, as is for instance foreseen in Ethiopia.

Figure 12 assumes that the construction phase is performed once the field development has been completed, a choice which allows the construction to occur when all the required wells have been drilled and tested. This reduces the risks related to an early design performed when only a fraction of necessary wells has been drilled and tested, but on the other hand requires a much longer time as the two phases are performed in series.

It is common in countries with experienced geothermal operators to perform the field development drilling and the EPC for the gathering system and the power plant almost in parallel. In particular when the funds are provided by an international funding institution (such as JICA, WB, etc.), an approach often followed includes the following steps within the same project:

- Start of field development by drilling and testing the planned production and reinjection wells;

- Update the previous resource assessment and feasibility study after the drilling and testing of a number of wells enough to cover all the prospect area; a flexible design of gathering system is performed to account for the uncertainties linked to the flow rate and discharge enthalpy of wells still to be drilled.
- Continue the field development drilling while performing the EPC of gathering system and power plant based on the updated feasibility study.

This approach considerably reduces both the cumulative time necessary for field development and power plant construction, and the risks connected to an early design of gathering system and power plant conducted on a few wells directly testing only a limited fraction of the reservoir volume.

1.4 Geothermal projects development in East Africa

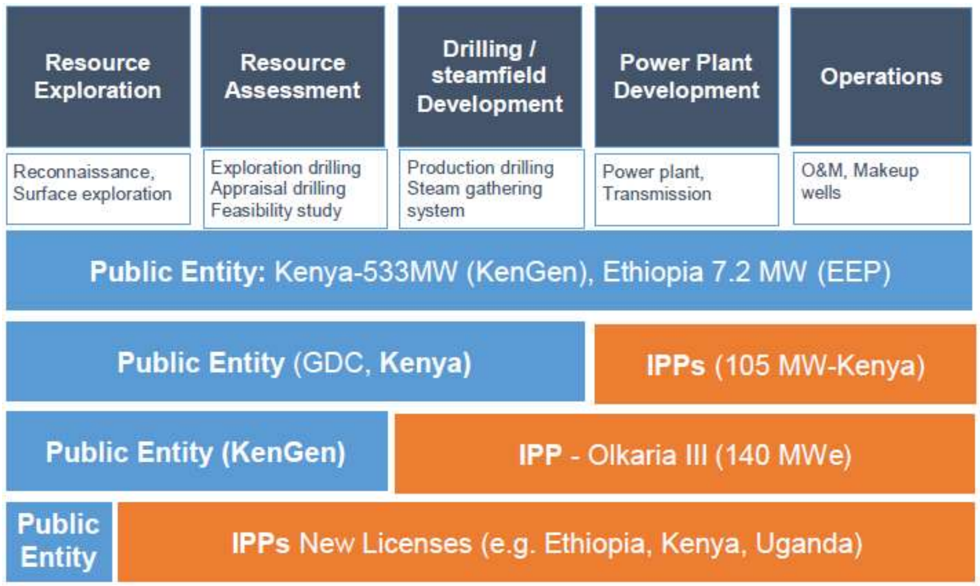
As far as the business scheme chosen for the development of geothermal resources is concerned, several schemes have been implemented in different countries with a well-developed geothermal industry. Related experiences represent useful examples for the development of geothermal resources in East Africa and are already successfully implemented in Kenya.

The business schemes followed until now in East Africa are summarized by Omenda (2018a) and shown in **Figure 14**. The initial business scheme followed was the full development of a geothermal resource by a Public Entity, like the initial development of Olkaria field in Kenya by KenGen. This approach has been followed in the past in many other countries either by electric power corporations or national oil companies such as ENEL in Italy, EDC in the Philippines, PGE and PLN in Indonesia, CFE in Mexico, ICE in Costa Rica, etc.

A second business model foresees that a Public Entity performs the Resource exploration and assessment and the Field development phases, those characterized by the highest mining and financial risks, while the power plant development and operation is awarded to an Independent Power Producer (IPP). This model has been chosen by GDC (Geothermal Development Company) for the Menengai field in Kenya, where the 105 MW field development was awarded on a competitive basis to 3 different IPPs (35 MW each). GDC performed the field development, constructed the steam gathering system and will manage the field exploitation by selling the steam to the IPPs. This approach is open to IPPs able to manage the EPC for the power plant and subsequently operate the power plant with a steam supply assured by the contract with the field operator. The IPP can be either a private company as well as a state-owned electricity utility: this is the case of geothermal fields in Indonesia operated by PGE (the national Indonesian oil company) who is selling the steam to PLN (the national Indonesian electric power producer) who in turn generates the electricity.

A third business approach limits the intervention of the Public Entity to the Resource Exploration and Assessment phases, while the IPP develops and constructs the field and the power plant and subsequently is in charge of both the well field and the power plant operation, normally for at least 25-30 years. This approach is limited to a few IPPs which are experienced geothermal operators acting internationally, such as Ormat, EDC, Reykjavik Geothermal (RG), Enel Greenpower. This approach has been followed by KenGen for Olkaria III 140 MWe field expansion, with the staged field development and power plant construction awarded to Ormat through OrPower 4 Inc.

Figure 14. Geothermal projects development in East Africa (Source: Omenda, 2018a)



The fourth business approach limits the Public Entity role to the Resource exploration phase with reconnaissance activities at regional scale and surface exploration of selected most promising prospects. Then all the subsequent activities are demanded to IPPs which in this case must be an experienced geothermal operator, or a JV between operators, acting internationally.

An example is the Tulu Moye geothermal project in Ethiopia, operated by TMGO (TM Geothermal Operations PLC, http://www.tmgeothermal.com/) a company belonging to Reykjavik Geothermal Ltd (RG), the Icelandic based Geothermal developing company, and Meridiam, a French based global investor and asset managing company.

Figure 14 shows that geothermal development for power generation in Eastern Africa was driven mainly by the governments through state corporations, but the trend has since shifted to IPPs developing geothermal projects from very early stages. This trend follows what basically occurred in many countries all around the world, with an increasing shift from public to private operators. Generally, apart for highly developed electric markets, a Public Entity is the final buyer of the generated electricity. This requires the signing of a Power Purchase Agreement (PPA) between the geothermal operator and the state-owned electricity utility. In addition to obligations relating to the sale and purchase of the power generated over the whole power plant operation period, the PPA usually sets out also the required design and outputs, and operation and maintenance specifications for the power plant.

Opening to private skilled operators should of course allow to speed-up the development of geothermal resources, which is one of the main targets of the East African governments.

1.5 Recognized obstacles to the development of geothermal resources utilization in East Africa

East Africa is characterized by the presence of the East African Rift System (EARS) with its Eastern and Western branches. While this geodynamic context creates high favourable conditions for the existence of geothermal systems at economically and technically drillable depths, with a global potential estimated at 20,000 MW (Omenda, 2018b), at present only Kenya has developed its geothermal resources with an installed electric power of about

865 MW, against estimated resources amounting to some 7,000 MW. Despite exploration drilling performed since the 80's in both Djibouti and Ethiopia, no power generation is at present active in both countries.

There are several reasons for the delay of geothermal resources development in East African countries, such as:

- the lack of clear and coherent legislative frameworks regulating the activities of both public and private investors in several countries.
- the lack of local technical and managerial skills able to conveniently support the exploration and exploitation of geothermal resources.
- the remoteness of many East Africa geothermal areas from developed O&G regions where most of the drilling contractors and service providers are based, and then the absence of infrastructures and logistic facilities supporting the drilling activities characterising well developed O&G markets.
- inadequate financing of the early stages of geothermal projects, commercial banks reluctance to participate in the exploration phase and the need for more risk reduction opportunities which facilitate the investment by both public and private operators.
- competition from other energy sources, such as Hydro in Ethiopia, which creates a challenging environment for geothermal projects in the region.
- the issue of remunerative price for the generated electric power in still poor developed national electric markets.

Several of the above obstacles are common to geothermal resources development, independently on the location of the resource, but some are more specific to East Africa.

In order to help East African countries to overcome the above issues, international organizations and financial institutions are actively collaborating with national governments to create the necessary legislative framework in each country, to facilitate the capacity building with the creation of excellence centres and the organization of dedicated courses and conferences.

On the other hand, financial and international institutions, such as WB, EU, NDF, AFD, AfDB, JICA, etc., are providing both grants and low interest loans to help public and private operators in the various steps of geothermal resource development, from the exploration surveys to the construction of power plants.

Legislative and administrative framework. A clear and coherent legislative framework about the ownership of geothermal resources, licensing for exploration and exploitation, permitting, environmental and social impact evaluation, technical regulations for drilling and testing, is fundamental in any country willing to explore and utilize its geothermal resources. Granting of exploration and exploitation rights should be based on the following three principles (Gehringer and Loksha, 2012): a clear legal and regulatory framework; well defined institutional responsibilities; and transparent, competitive, and non-discriminatory procedures, including adequate measures for controlling speculative practices.

This allows national and international investors to take their decisions in a clear contest which reduces financial and operation risks. Clear exploitation rights assured by a utilisation license are fundamental for geothermal field exploitation which is characterised by high initial investments, low operating and maintenance costs and revenues shared over a 25-30 years exploitation period. Administrative issues such as licensing, permitting and environmental assessment need to be tackled carefully by project developers, as they might impact a geothermal project by causing unnecessary delays. On the other hand, governments should ensure that their regulations establish a transparent and straightforward process that will foster the deployment of new projects.

An example of a new legislative framework sponsored by international institutions is that recently developed in Ethiopia with the following steps:

- Geothermal Resources Development Proclamation No. 981/2016;
- Geothermal Resource Development Council of Ministers Regulations No. 453/2019;
- Directives about licensing, permitting, geothermal drilling, etc., issued by the Ethiopian Energy Authority, the Government institution in charge of the management of permitting process and of the preparation of all necessary technical directives.

It is worth to mention that the Ethiopian Regulations No. 453/2019 foresees that EEA *shall establish a process for geothermal resources data collection and management in cooperation with GSE* (Geological Survey of Ethiopia) *or a successor entity responsible for geothermal data acquisition, management and accessibility*. *EEA shall also establish and maintain a Register of Geothermal Resources documents* for the management of licensing and permitting process. The owners of geothermal licenses shall periodically report to EEA about the results of their activity and the raw data collected during surface surveys, well drilling and reservoir exploitation. The availability of information about the geothermal resources to potential developers and investors is believed to be a key element in supporting the development of geothermal projects or programs (Gehringer and Loksha, 2012).

Lack of skilled resources. Capacity building is felt as a vital factor for the proper development of geothermal resources in East Africa (IRENA, 2018). UNEP/ARGeo conducted a skills gap analysis of geothermal technical personnel in African Countries (UNEP and ARGeo, 2015) focused on 4 phases, namely prefeasibility, feasibility, development and utilization. The results of the survey, discussed in detail in chapter 2.1.2, pointed out that in order to fulfil the planned targets in terms of installed power between 2015 and 2030, the following required fractions of professional skill should be covered: 70% of geoscientists (geologists, geophysicists, geochemists), 91% of reservoir engineers, 88% of drilling engineers, 84% of plant engineers.

ARGeo concluded that overseas training facilities, such as UNU-GPT in Iceland, and the organisation of dedicated workshops and courses in various African countries were not enough to train the required number of professionals. Thus, in order to address the challenge of technology transfer, African countries planned to set up the Africa Geothermal Centre of Excellence (AGCE) in order to build and strengthen their institutional and infrastructural capacities and create a critical mass of geothermal scientists and engineers in the continent. The AGCE has been established in Kenya under the Kenyan law, and is now using the existing training facilities of GDC and KenGen.

In addition to technical skills requirements, experiences gained in several East Africa countries suggest that the development of adequate management skills is also fundamental for national institutions and companies. In fact, government agencies outside Kenya are short of commercial expertise and experience (in areas such as financial analysis, market analysis, project management and business planning). Capacity building should also be focused on supporting decision making, not only imparting technical or commercial knowledge. Geothermal energy is a peculiar business sharing the activities and mining risks typical of the O&G industry and the construction and operation phases typical of the power industry. Managers able to work in this contest are then necessary.

Moreover, internal procedures of national institutions and companies, such as those for the procurement of services and goods, shall be adequate for the requirements of the geothermal industry. The use of procurement procedures built for different business environments are proving to be inadequate when applied to the procurement of drilling services, a global market having its own almost standardised procurement and contracting procedures.

Remoteness of many East Africa geothermal areas. With the exception of Kenya, were geothermal resources are well developed, in all the other East Africa countries the geothermal industry is still at an early stage of development. In addition, limited O&G exploration and exploitation activities are in place in East African countries. Thus, headquarters and logistic basis of drilling contractors and service providers are not present, as well as the infrastructures and facilities characteristic of well-developed O&G and geothermal regions. This situation makes drilling in these countries riskier than drilling in countries with O&G activities, probably making drilling tenders in East Africa less attractive for many O&G contractors even in a period of drilling market crisis as the present one (https://rigcount.bakerhughes.com/intl-rig-count/). Drilling contractors accepting the additional risks linked to these countries, probably include a compensation of those risks in their offered prices which may result higher than those expected for well-developed geothermal drilling markets.

Financial barriers. Geothermal power plant development involves substantial capital requirements due to exploration drilling costs, for which it can be difficult to obtain bank loans. Since geothermal exploration is considered high risk, developers generally need to obtain some type of public financing. This risk is derived from the fact that capital is required before confirmation of resource presence or exploitability, and therefore before project profitability can be determined as basically shown in Figure14/3.

Governments can reduce this risk and the cost of capital for private developers in a number of ways. For instance, they can create public companies that exploit geothermal resources and provide private companies (that install power plants and supply electricity to their customers) with the required steam.

Other risk mitigation instruments include cost-sharing for drilling and public-private risk insurance schemes. With sufficient resource information, including seismic events, surface tectonic lineaments, and deep drilling data (which national or local governments can make available to developers), and reliable conceptual models of the underlying geothermal system and groundwater resources, risks could be reduced and financial barriers could be further eased, accelerating geothermal development (Gehringer and Loksha, 2012).

Approaches to risk mitigation

Approaches to risk mitigation for geothermal projects are discussed by JRC (2019a) which makes reference to an overview report by ESMAP (2016a). According to them, geothermal power plants development is hampered by:

(i) the need for significant up-front capital investment long before revenue is earned from electricity sales;

(ii) the high level of resource risk up to the early drilling stage.

The entire development process might take two to five years, from surface-based explorations to the confirmation of the resource. Another three to five years is required for additional drilling to build the well field and construct the power plant before operation can commence.

Incentive schemes drawing on public support that help move risk capital into geothermal exploration drilling include:

- Government takes on the full resource and other project risks by acting as the total project developer (exploring, discovering, building and operating the project), through state-owned enterprises or other government-backed entities. This was the original approach in Kenya with the public power utility KenGen.
- Cost-shared drilling for mobilising private development, where some or all of the risk of drilling to develop the steam field is shifted to the public sector. This is the second step chosen by the Gov. of Kenya with the creation of GDC (Geothermal Development Company) having the mission to perform surface exploration, exploratory drilling, field development and operation, while selling steam to private IPPs (Independent Power Producers).

- Geothermal resource risk insurance that looks to pool exploration risks across a portfolio of development.
- Early-stage fiscal incentives (exemption from duties, tax credits, etc.) that lower the financial exposure developers would face during exploration drilling.

Financial risk management schemes

A Geothermal Risk Insurance Fund is seen as an appealing public support measure for overcoming the geological risk (JRC, 2019a). As costs decrease and markets develop, the private sector will be able to manage project risks with, for example, private insurance schemes, and attract private funding.

With the notable exception of a few European market participants operating in well-developed geothermal regions, project developers have very little capability to manage the financial risk owing to the poor knowledge of the deep subsurface, lack of technological progress and high costs. In effect, the probability of success/failure weighted net present values of project cash flows tend to be overly negative, thus effectively shutting out private capital from investing in geothermal energy.

However, with technology development (increasing the probability of success of finding and developing geothermal reserves) coupled with experience and thus reductions in cost, project developers will eventually be able to accept and, where appropriate, transfer project risks (technical, economical, commercial, organizational and political) in such manner that private funding will become available. Until then, a Geothermal Risk Insurance Fund is seen as an appealing public support measure for geothermal.

Support schemes. Public support for geothermal energy it is meant to mobilise private financing in a difficult investment climate. The economic and financial crisis started in 2008 has indeed affected investment in clean energy. The picture appears already to be complicated, and it should be added that geothermal energy is a capital-intensive technology that takes some years to develop. Such a barrier can be tricky to overcome, especially with banks exclusively looking for low to zero risk.

Risk mitigation mechanisms

Innovative risk mitigation mechanisms targeting the early phases of a project can be crucial to unlocking investment (IRENA, 2018).

Risk mitigation instruments already available in the region and worldwide were reviewed during the IRENA workshop "Geothermal Finance and Risk Mitigation in East Africa". Existing direct finance options – for example from the Geothermal Risk Mitigation Facility – have been important in attracting interest from the private sector and improving the understanding of the geology through the financing of surface studies. However, it seems that the time and effort required to complete the application process was onerous, owing to limited staffing and experience of applicants.

The Geothermal Risk Mitigation Facility for Eastern Africa (GRMF) is providing grants covering a variable costs fraction for infrastructure construction, exploration surveys and exploration drilling, that is the phase characterized by the higher mining risks. Grants have already been awarded to projects located in Djibouti, Ethiopia, Kenia, Uganda, Tanzania and Comoros. GRMF is discussed in detail in chapter 2.3.1.

Equity and other funding for appraisal drilling, together with public–private well productivity insurance schemes, could further encourage private sector involvement and facilitate the successful development of geothermal projects, including medium temperature systems. Regarding well-productivity insurance, it has been observed that only a few geothermal power plants were developed globally using this instrument, with some failed attempts in Germany, Turkey and the United States. However, public–private risk mitigation insurance schemes, together with complementary investment and operating aid, have been successful in supporting the market uptake of geothermal heating projects in France and the Netherlands.

High premium and transaction costs were reported to be obstacles for insurers due to small markets and the intense due diligence required by each project. However, efforts are underway to explore various insurance scheme designs such as a portfolio approach (insuring the specific productivity of several wells in a prospect) and backstopping by public concessional funds (e.g. Mexico). In this framework, the structure of the proposed Geofuture Fund depicted in **Figure 15** was presented during the IRENA workshop. The proposal, which was shortlisted by the Green Climate Fund, promises to make it easier for developers in Kenya and Ethiopia to raise equity.

Figure 15. Geofuture Fund proposal (Source: IRENA, 2018)

Activity addressed	Pillar 1 Direct finance			Pillar 2 Risk mitigation		
	Coverage	Type	Sectors	Coverage	Type	Sectors
Surface studies	✓	40% CL	Any	✗	N/A	N/A
Infrastructure	✓	40% CL	Any	✗	N/A	N/A
Exploratory drilling	✓	40% CL	Any	✓	60% CL	Pri & PPP
Appraisal drilling	✗	N/A	N/A	✓	60% CL	Pri & PPP

Intervention type key
NRG Non-recoverable grant
CL Convertible loan
N/A Not applicable

Sector key
Any Any sector (public, private or PPP) eligible
Pri Private sector eligible
PPP Private private partnership eligible

Technical approaches to risk reduction

The IRENA (2018) workshop highlighted that sound exploration, wellhead technology application and integrated resource use could help to reduce risks and improve projects bankability.

The following elements, deriving from experiences and lessons learn, are believed to reduce risks and improve the bankability of geothermal projects.

- **Sound exploration for high-quality geological data**: prior to the more capital-intensive drilling phase, sound exploration through adherence to best international practices to conduct and manage surface surveys and thorough data analysis from the project site should be considered the first risk mitigation tools available. Dedicated appropriate technical assistance is undoubtedly critical to improving the quality and interpretation of geological data during the first phase of surface exploration.
- **Linking technical and commercial analyses** to the development of realistic pre-feasibility studies prior to making major investments. Pre-feasibilities studies are customarily performed after the execution of surface exploration studies with the main goal to support the decision to proceed with the expensive drilling of deep exploratory wells. Sometime too optimistic approaches based on geoscientific studies and not adequately supported by a technical and commercial analysis of the next drilling phase, were the premises for unsuccessful exploration drilling.
- **Generating early revenue** through wellhead generators: the application of wellhead technology has dramatically improved the economics of some geothermal projects in Kenya and elsewhere. Generated electricity from single production wells brings in cash flow early in the project and the possibility to relocate the wellhead plant once there is enough steam available for a more efficient, large scale power

plant. As the operation of the wellhead unit becomes very important to assessing the economic feasibility of mobile wellhead power plants, its application should be carefully considered at the beginning of the field development. It appears that installing wellhead power plants is advantageous when an early electric generation can be obtained during a long-term field development in quite large fields, and when the wellhead power plants can be relocated on another field or field sector when the final power plant starts its operations. From this point of view the KenGen positive experience in Olkaria is quite significant (Saitet and Kwambai, 2015; Kibet and Bwoma, 2012).

- **Supplement project revenues** through direct use applications and sale of other by-products such as CO_2, silica, etc. Direct uses include aquaculture, horticulture and food drying, industrial processes, spas, etc., all of which can contribute to the development of economic activities in the areas nearby the resource location, thereby also facilitating social acceptance. For instance, in Kenya KenGen is building a spa at the Olkaria field while GDC has set up a Demonstration Unit in Menengai comprising four pilot projects utilizing geothermal heat: a mini greenhouse, an aquaculture facility, a Containerized Laundry, and a Dairy Unit (Nyambura, 2016).

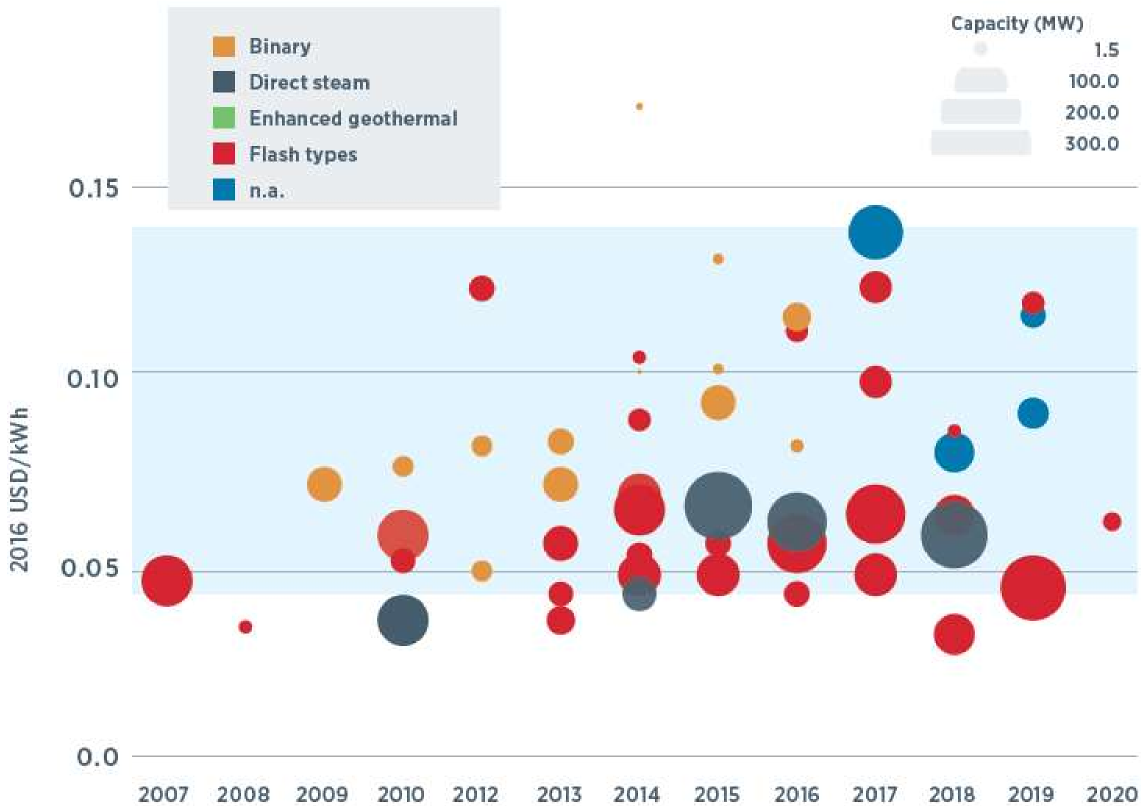
Competition from other energy sources. Geothermal energy shall be as much as possible competitive with other energy sources, either other renewables or fossil fuels. **Figure 16** (IRENA, 2017) shows the estimated levelized cost of electricity generation (LCOE) by geothermal plant technology for a 25-year economic life, O&M cost of 110 USD/(kW y), capacity factors based on project plans (or national averages if data were not available) and the capital costs outlined in Figure 8/3. The Figure shows how the larger flash or direct steam plants allows to achieve lower LCOE than the smaller ORC plants, and that most of the plants allows a LCOE lower than about 0.08 USD/kWh, which is competitive with electricity generated with fossil fuels.

Figure 17 shows the LCOE (for unsubsidized analysis) estimated by Lazard (2019) for conventional generation with fossil fuels and renewables, which let Lazard to state that selected renewable energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances. The LCOE for geothermal energy has a range between 0.069 and 0.112 USD/kWh, which is slightly higher than that estimated by IRENA (2017), with costs expressed in 2016 USD.

According to Lazard (2019), geothermal energy generation is definitely cheaper than Gas peaking and Nuclear and equivalent to the cheaper generation which can be obtained using Coal. Only the Gas combined cycle generation is definitely cheaper than the geothermal generation.

With respect to Solar and Wind, geothermal generation is cheaper than Solar PV for residential and Solar thermal with storage, and in the lower range of LCOE for Solar PV for rooftop and community applications. Large Solar PV and Wind are on the other hand definitely cheaper than geothermal energy. This might be a problem for geothermal energy development in East Africa as the solar resources in the region are substantial. Due to the expected raise of electric power needs in the region, all the renewables will for sure give their contribution, but cheaper energy sources like Solar and Wind not affected by the mining risks of geothermal energy will likely be preferred by many international and national investors.

Figure 16. Estimated levelized cost of electricity generation (LCOE) by geothermal plant technology for a 25-year economic life. The blue band represents the range of costs for fossil fuel power generation. (Source: IRENA, 2017)



An evaluation of LCOE specific for renewable energies is that presented by IRENA (2019) with reference to year 2018. **Figure 18** shows the LCOE for all the major renewables sources with a comparison of changes between 2010 and 2018. The average LCOE of Hydro is lower than that of geothermal energy, and this is a constraint for geothermal development in East Africa countries rich of Hydro resources, like for instance Ethiopia. Geothermal energy experienced an increment of LCOE between 2010 and 2018 at the global scale also due to the diffusion of ORC plants characterized by a higher LCOE. On the other hand, technological improvements on rapidly growing technologies such as Solar PV and Onshore Wind are the main reasons for the decline of their LCOE between 2010 and 2018.

Thus, the competitiveness of geothermal energy against Hydro, Solar PV and Onshore wind in East Africa countries shall be taken properly under consideration.

Figure 17. Levelized Cost of Energy Comparison. Unsubsidized Analysis (Source: Lazard, 2019)

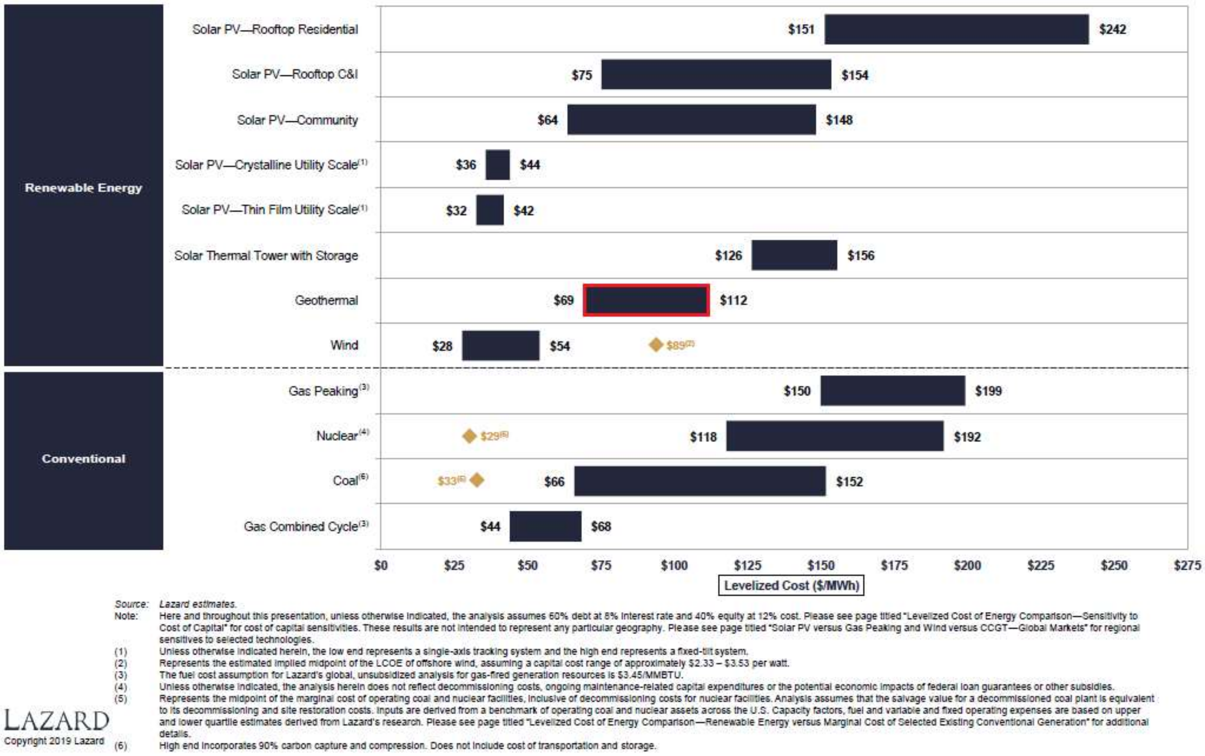
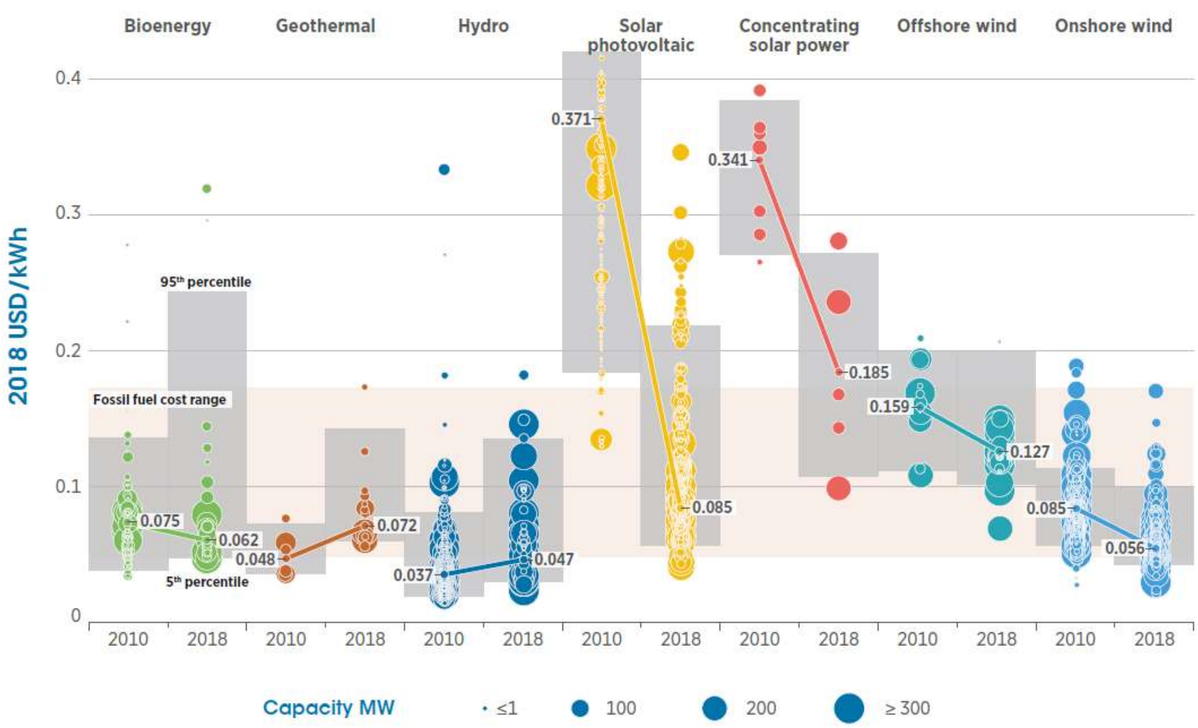


Figure 18. Global LCOE of utility-scale renewable power generation technologies, 2010–2018. Real weighted average cost of capital (WACC) is 7.5% for OECD countries and China and 10% for the rest of the World. (Source: IRENA, 2019)



2 International stakeholders

International Stakeholders actively supporting the development of geothermal resources in East Africa are many, involved with different roles and at various stages of the geothermal resource development chain. Many of them are collaborating on common initiatives often sharing funding contributions and management responsibility.

While any reasonable effort has been assured to collect the relevant information within the time constraint of the present study, following chapters 2.1 to 2.18 dealing with the major international stakeholders involved in the development of geothermal resources in East Africa cannot be complete and exhaustive because of the so many stakeholders acting in over 10 different African countries.

In addition, while most of the general information is available to the public through the WWW, the details on specific initiatives are often not readily available and, on the other hand, the published information is not always updated. More comprehensive and updated info could be collected by directly asking the institutions involved both at the international and national levels. This approach was not foreseen for the present study.

While a summary of main international stakeholders is given here below, including their mission, objectives and main activities, the discussion about stakeholders acting at national level is mainly supplied on chapters 3.1 to 3.11 relevant to the geothermal energy status in each East African country covered by the present study.

2.1 United Nations (UN)

The United Nations (https://www.un.org/) is an international organization founded in 1945, currently made up of 193 Member States. The mission and work of the United Nations are guided by the purposes and principles contained in its founding Charter.

The UN system, also known unofficially as the 'UN family', is made up of the UN itself and many programmes, funds, and specialized agencies, all with their own leadership and budget. The programmes and funds are financed through voluntary rather than assessed contributions. The Specialized Agencies are independent international organizations funded by both voluntary and assessed contributions.

Historically, UN were involved in the development of geothermal resources worldwide since the ‘70s, when they organized the Symposium on the Development and Utilization of Geothermal Resources in Pisa, Italy (UN, 1970). The **United Nations Development Program (UNDP)** was the major UN player in geothermal development worldwide.

UNDP supports countries in their efforts to successfully address diverse development challenges, framed around three broad settings which require different forms of support:

- Eradicating poverty in all its forms and dimensions;
- Accelerating structural transformations for sustainable development;
- Building resilience to crises and shocks.

These three development challenges often coexist within the same country, requiring tailored solutions that can adequately address specific deficits and barriers. Underpinning all three development challenges is a set of core development needs, including the need to strengthen gender equality and the empowerment of women and girls, and to ensure the protection of human rights.

Since the ‘70s, UNDP co-financed several geothermal projects in Latin America, Far East and in East Africa to support the development of geothermal resources in developing countries. It sponsored an important survey over the entire Rift System within Ethiopia (UNDP, 1973) which was fundamental in point out all the major geothermal prospects worth of further more detailed exploration.

A joint Geothermal Project by the **UNDP** and the Government of Kenya (GoK), represented by the East African Power and Lighting Company Ltd. (EAPL) was initiated in the early

1970's in the Rift Valley of Kenya. Geoscientific work was carried out between Olkaria and Lake Bogoria, and Eburru in 1971 and 1972. The work mainly consisted of geological mapping, hydrogeological surveys, gravity studies and infra-red imagery surveys.

By 1972, the resource within Olkaria was the most prospective and hence a decision was taken to concentrate the geothermal development efforts at Olkaria area (80 km^2). A technical review meeting at the end of 1972 recommended drilling of four deep (~ 2,200 m) exploratory wells in Olkaria area. In 1973, drilling of the four wells commenced with funds from UNDP. By 1976, six wells (well OW-1 to OW6) had been drilled. These wells were drilled by a rig owned by the EAPL company, owned by the then East Africa Community's three countries (Kenya, Uganda and Tanzania). A feasibility study on reservoir assessment, steam utilization for power generation, effluent, disposal, by product use and environmental impact of the development provided promising results. The study recommended the development of a 2x15 MW power station, thus definitely starting the development of the present Greater Olkaria geothermal field.

In 1986 UNDP financed the project management component of the **Djibouti Geothermal Exploration Project** during which 2 deep wells were drilled in the Hanlè plain and 4 deep wells were drilled in the Asal Rift (Aquater, 1989).

UNDP has published in Sep. 2019 a Request for Proposals for the Recruitment of an international consulting firm accompanied by national consultants to update the renewable energy policy in the **Union of the Comoros**. In support of a Comorian government's initiative, the UNDP mobilized funding from the Global Environment Facility (GEF) to finance the "Sustainable Development in the Comoros" Project through the promotion of technical resources in geothermal energy based in the Geological Survey of Comoros (BGC). In this context an international consulting firm, accompanied by national consultants, shall revise the legal framework of the energy sector. in order to adapt it to the new orientations of the Government. The Geothermal project is structured in 3 components:

- 1: Policy, Regulatory, Legislative and Financial Instruments of "Derisking" for the Development of Geothermal Energy.
- 2: Preparation and development of geothermal energy upstream.
- 3: Knowledge Management and Investment Promotion.

UNDP has also advertised in Sept. 2019 an open job position for an **International Consultant** "Senior Technical Advisor"/Sustainable Development in the Comoros through the promotion of geothermal energy resources. The Technical Advisor will be responsible for assisting the Project team in the preparation of the Work Plan and the smooth implementation of the Work Plan in accordance with the UNDP Implementing Regulations, as well as in the development of a mobilization plan.

Green Climate Fund, IRENA, Sustainable Energy for All (SEforAll) and UNDP announced on Sept. 2019 the **Climate Investment Platform (CIP)** to advance low-carbon energy transition and raise climate ambition. In response to country needs to mobilize low-carbon, climate-resilient investments, a new announced global public good will aim to increase the flow of capital in developing countries to meet climate ambitions. The **CIP** is an inclusive partnership welcoming all stakeholders from governments and international organizations to the private sector to scale-up climate action and translate ambitious national climate targets into concrete investments on the ground. With energy accounting for two thirds of total greenhouse gas emissions, the platform's first service line is dedicated to the global transition to clean energy. Other service lines, such as adaptation, land use, cities and infrastructure shall be launched in the first quarter of 2020. By decluttering and streamlining support to developing countries, the platform aims to accelerate action and advance climate investment in developing countries.

The service offered by the CIP covers four key building blocks along the climate finance value-chain: i) supporting governments to specify ambitious energy targets and scale up their Nationally Determined Contributions (NDCs), ii) establishing well-designed, implemented and enforced clean energy policies and regulations, iii) financial de-risking of energy projects, and iv) a market-place to connect clean energy investors and project sponsors. CIP will hopefully support the geothermal development in East Africa.

The **United Nations Economic Commission for Europe (UNECE)** was set up in 1947. It is one of five regional commissions of the United Nations. UNECE's major aim is to promote pan-European economic integration. UNECE includes 56 member States in Europe, North America and Asia. However, all interested United Nations member States may participate in the work of UNECE. Over 70 international professional organizations and other non-governmental organizations take part in UNECE activities.

As geothermal energy development at global scale has been constrained by a lack of clear global assessment guidelines and standards, UNECE decided to sponsor the development of a globally-applicable, harmonized standard for reporting geothermal resources based on UNFC. The United Nations Framework Classification for Resources (UNFC) is a universally acceptable and internationally applicable scheme for the sustainable management of all energy and mineral resources.

The Expert Group on Resource Classification requested the expertise of the International Geothermal Association (IGA) to provide specifications for the application of UNFC to geothermal energy resources. This led to the publication of the Specifications for Application of UNFC-2009 to Geothermal Energy Resources (UNECE and IGA, 2016).

IGA, WB and IRENA organized an UNFC Geothermal Specifications workshop in Addis Ababa, Ethiopia between 5 and 7 February 2019. The attempt is to push the use of UNFC resource classification framework for all the geothermal prospects in East Africa.

The **United Nations Environment Programme (UNEP)** is the leading global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system, and serves as an authoritative advocate for the global environment. UNEP mission is to provide leadership and encourage partnership in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations.

UNEP work is categorized into seven broad thematic areas: climate change, disasters and conflicts, ecosystem management, environmental governance, chemicals and waste, resource efficiency, and environment under review. In all its work, UNEP maintains its overarching commitment to sustainability. The major accomplishment of ENEP for the development of geothermal resources in East Africa is the African Rift Geothermal Facility (ARGeo) which is described in detail in chapter 2.1.2.

2.1.1 Geothermal Training Program (GTP)

The Geothermal Training Programme (https://www.grocentre.is/gtp/about-gtp/mission) was a postgraduate training programme, aimed at assisting developing countries in capacity building within geothermal exploration and development. The programme consisted of six months annual training for practicing professionals from developing and transitional countries with significant geothermal potential. Priority was given to countries where geothermal development is under way, in order to maximize technology transfer.

The programme has operated in Iceland since 1979 and was hosted by the National Energy Authority (Orkustofnun). From its establishment until Dec. 31 2019, it was a cooperation between the United Nations University (UNU) and the Government of Iceland. As of Jan. 1, 2020, GTP and UNU decided to part ways, and GTP joined hands with the other three training Programmes in Iceland (Fisheries, Land Restoration, and Gender Equality Studies Training Programmes) to form GRÓ: the Centre for Capacity Development – Sustainable Use of Natural Resources and Societal Change in Iceland.

The Centre, through the Programmes, will, as before, aim to strengthen organisational, institutional and individual, capacities in developing countries, including the focus on

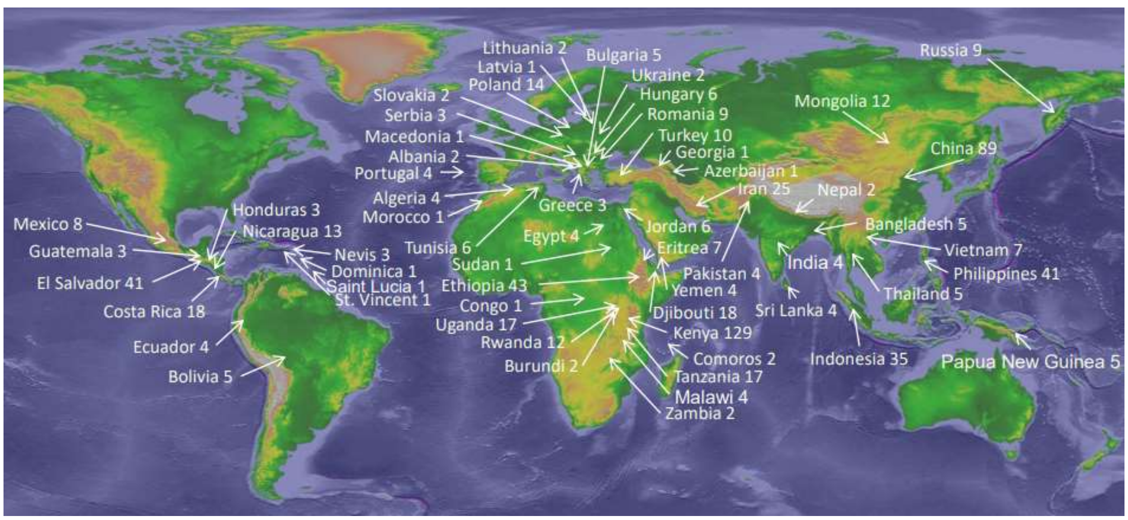
“Promoting the utilisation and sustainable management of reliable, economically viable, and environmentally sound geothermal energy resources (GTP)”.

About the results achieved till the end of 2019 by the GTP:

- 718 Fellows have graduated from the 6-month Training Programme, among whom 169 Women; Fellows coming from Africa were 40% of the total.
- Fellows from 63 Countries have been involved.
- 27 Millennium Development Goals/Sustainable Development Goals (MDG/SDG) Short Courses held since 2005.
- 43 Customer Designed Courses held since 2010.

The origin of the 6-month Training Programme Fellows, at the end of 2018, is documented in **Figure 19** (Ómarsdóttir, 2019). Among the others, 129 were coming from Kenya, 43 from Ethiopia, 18 from Djibouti, 17 from Tanzania and Uganda, and 12 from Rwanda.

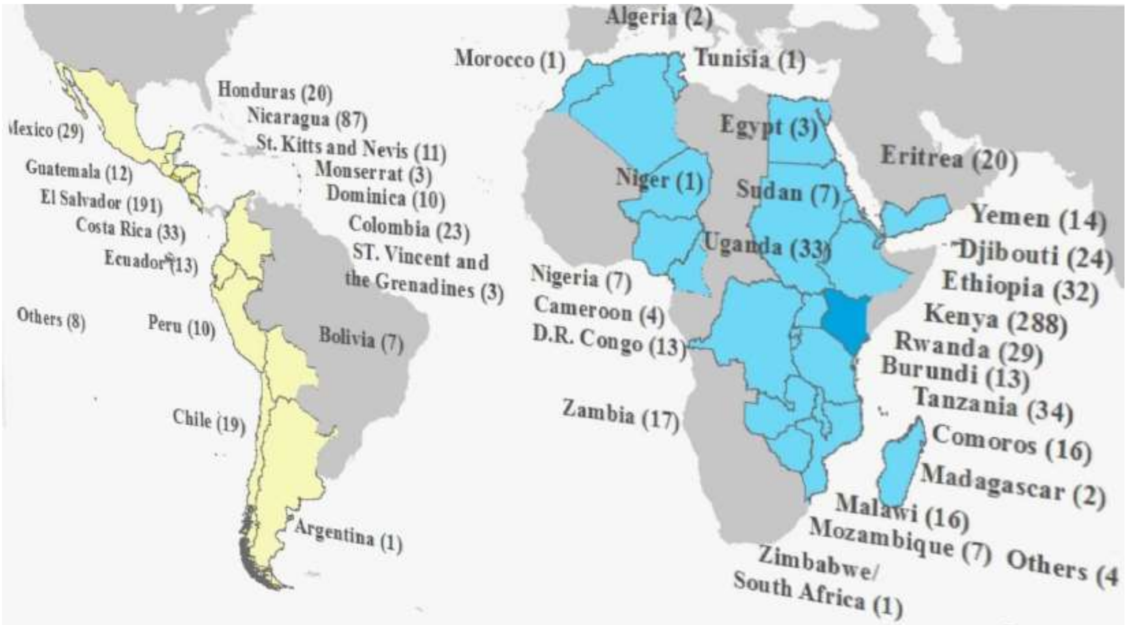
Figure 19. UNU-GTP Fellows in Iceland 1979-2018. (694 from 61 Countries) (Source: Ómarsdóttir, 2019)



GTP was also offering MSc and PhD studies carried out at the University of Iceland or at Reykjavik University, with costs associated with living in Iceland covered by UNU Fellowships.

GTP was also performing Annual Short Courses in two key geothermal regions, i.e. East Africa and Latin America, as a special contribution of the Government of Iceland through UNU-GTP (till the end of 2019). Courses held annually in El Salvador and Kenya reached over 1,200 participants trained since 2005. Participants from east Africa Countries came mostly from Kenya (288), Tanzania (34), Uganda (33), Ethiopia (32), Rwanda (29), and Djibouti (24) as shown in
Figure 20. The 3½ week long short courses on “Exploration for Geothermal Resources” held in Kenya in cooperation with KenGen and GDC reached a total of 708 trained participants.

Figure 20. Fellows of Annual Short Courses held since 2005 in El Salvador and Kenya (Source: Ómarsdóttir, 2019)



GTP was also offering Customer-designed courses & training since 2010. They were sponsored by the customer or some other support mechanism. Could be either a general geoscientific course or specialized on a subject. Examples of courses performed in East Africa, mainly in Kenya, Ethiopia, Djibouti and Rwanda, are as follows:

- Training services in Geology, Geophysics and Geochemistry (4 weeks) GDC, Kenya, 2010.
- Course on Geothermal Technology (13 weeks) KenGen, Kenya, 2012.
- Advanced training in Borehole Geology (4 months) EWSA, Rwanda, 2013.

The above figures show how the GTP became, and will likely be for the coming years within a different organization, a powerful program to supply highly specialized training for students, professionals and companies of East Africa Countries. It was an important contribution to the capacity building in the field of geothermal energy exploration and exploitation in East Africa.

2.1.2 African Rift Geothermal Facility (ARGeo)

The African Rift Geothermal Development Facility (ARGeo) Project is a GEF funded project being implemented by United Nations Environment Programme (UNEP). ARGeo was officially launched in November 2010 at the opening session of the Third African Rift Geothermal Conference (ARGeo-C3) in Djibouti.

UN Environment ARGeo project (https://theargeo.org/index.php) aims at supporting the development of the large untapped geothermal resource potential in the Eastern Africa region with the main objective of reducing the risks associated with the resource's exploration. ARGeo also aims to reduce greenhouse gas (GHG) emissions by promoting the adoption of geothermal energy in the region.

ARGeo shall also help to demonstrate that the geothermal resource is reliable, cost effective and indigenous as compared to other sources of power in the Eastern Africa region. The utilization of the resource in agriculture and industry will also be promoted.

The expected outputs are as follows:

- A number of geothermal fields explored in the region.

- Geothermal resource sites with high energy potential identified and investment catalysed.
- Skilled manpower in geothermal resource investigation and management of projects developed.
- Clear and coherent Geothermal policy, legislation and institutional framework developed.
- Regional Networking hubs and information based Geothermal database created.

ARGeo project objective is to encourage both Private and Public developers to accelerate development of geothermal resource in the East Africa Region. ARGeo project has 6 member countries namely: Eritrea, Ethiopia, Kenya, Rwanda, Tanzania and Uganda. Furthermore, under the framework of "Regional Networking and Capacity Building components", ARGeo targets other 7 geothermal potential countries which are Burundi, Comoros, Djibouti, DR Congo, Malawi, Mozambique, and Zambia.

Partners of ARGeo projects are:

- African Union Commission.
- Germany Development Bank (KfW).
- Icelandic International Development Agency (ICEIDA).
- German Federal institute of Geosciences and Natural Resources (BGR).
- United Nations University - Geothermal Training Programme (UNU-GTP).
- ARGeo Member Countries.

The ARGeo Project has two major components:

- Regional Networking, Information Systems, Capacity Building, Policy Advice and awareness creation.
- Technical Assistance for Surface Exploration Studies.

UNEP/ARGeo conducted a skills gap analysis of geothermal technical personnel in African Countries (UNEP and ARGeo, 2015) focused on 4 phases, namely prefeasibility, feasibility, development and utilization. For each phase the main activities involved were identified and related needed expertise listed. In February 2015, a detailed questionnaire was delivered to experts/focal points from fourteen African countries. Response was received from twelve countries, namely: Comoros, Djibouti, DRC, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, and Zambia. Attempts to receive feedback from South Sudan and Burundi were not successful.

Respondents/participants were asked to quantify the scale of their current need for additional employees who could carry out each of specific skills categorized within technical and support skills.

The following information was collected on the basis of the questionnaire distributed to all relevant agencies:

- Strategic geothermal development plan in the coming 15 years.
- Current Geothermal workforce in the region (by age/gender/ qualification).
- Required (existing and new) expertise in the coming 15 years (by age/gender/qualification).

The analysis of questionnaire results was made in terms of the following items:

(i) Strategic geothermal development plan in the coming 15 years. The strategic geothermal development plan for each country is described in terms of five-year period intervals.
(ii) Current Geothermal workforce in the region (by age/gender/qualification).

(iii) Current trained geothermal experts in the region (by age/gender/ qualification).
(iv) Required (existing and new) experts in the coming 15 years (by age/gender/qualification).

The strategic plan for geothermal resource development in the region was categorized into two groups: 1) countries with plans to generate power from geothermal energy resource in the next 5 years: Comoros, Djibouti, Ethiopia, Kenya, Rwanda, and Tanzania; and 2) countries with plans to identify geothermal prospect areas, including drilling, in the next 5 years: Burundi, Democratic Republic of Congo (DRC), Eritrea, Malawi, Mozambique Uganda and Zambia.

First observation is that at the beginning of 2020, that is after 4.5 years from the questionnaire, none of the countries of first group (apart Kenya which was already generating electric energy and was also able to install new plants) was actually capable to reach the expected target of power generation from geothermal resources. In some way this seems to indicate that planning of geothermal development is often characterized by a too optimistic approach.

Interesting are the results related to the current workforce in terms of geoscientists (geologists, geophysicists, geochemists) and engineers (drilling, reservoir and power plant) as shown in **Figure 21**, and technicians in the same areas as shown in **Figure 22**. Kenya obviously shows a consistent number of geoscientists and engineers as should be reasonably expected for a Country with over 700 MW installed power. All the other Countries show a quite limited number of professionals mainly limited to geoscientists which are of course always involved in the first stages of geothermal exploration with surface studies. Almost no reservoir and drilling engineers, fundamental in the feasibility and development phases which were indeed planned in 2015.

The exceptional high number of drilling engineers (over 45) declared by Ethiopia is probably due to a misunderstanding in the questionnaire interpretation. At the time EEP and GSE were committed to drill a couple of wells in the Aluto Langano field. That number is probably including the drilling crew personnel which is, on the other hand, not declared among the available technicians (see **Figure 22**).

Interesting is also the case of Rwanda which declared 10 geoscientists and reservoir engineers and 5 drilling engineers, despite the fact that only surface studies were completed in Rwanda till 2015. Declared figures shall represent the engineers needed in the planning and performance of feasibility studies which involve the drilling and testing of deep wells and a first evaluation of the available resource. Actually, no feasibility study with the drilling of deep wells was performed in Rwanda from 2015 till the end of 2019.

Figure 21. Geothermal Workforce in 9 East Africa countries: Current Technical Staff in terms of geoscientist and engineers (Source: UNEP and ARGeo, 2015)

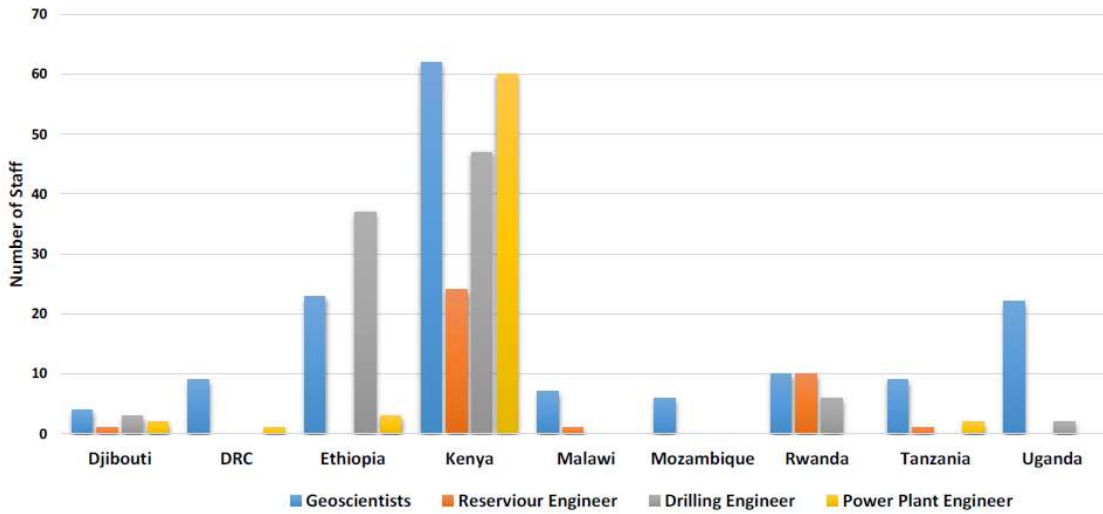
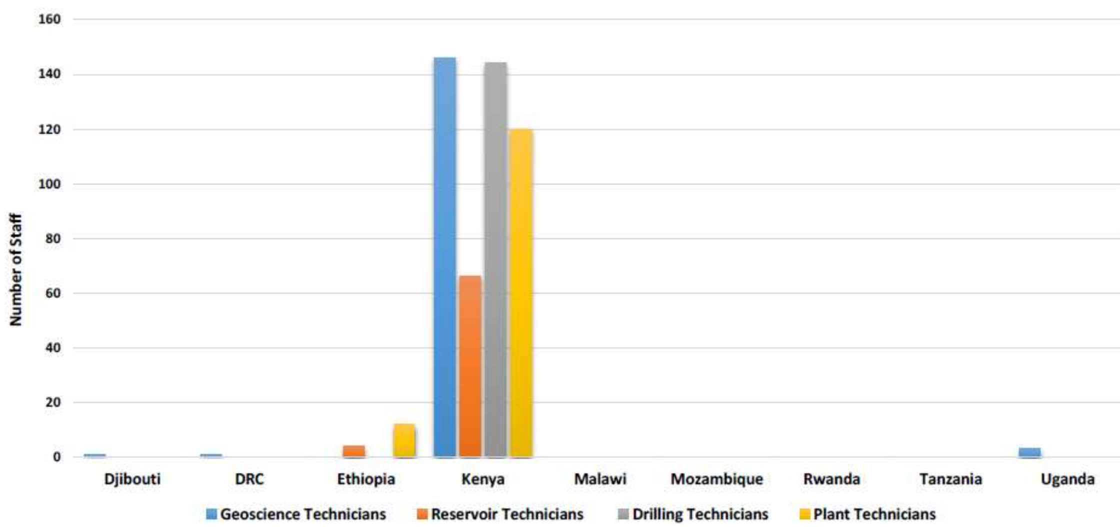


Figure 22. Geothermal Workforce in 9 East Africa countries: Current Technical Staff in terms of technicians (Source: UNEP and ARGeo, 2015)



The situation in which skilled personnel is available, but no activities in which that personnel should be involved are actually done, is potentially dangerous. Under-used skilled personnel have the tendency to move looking for adequate jobs in other companies, industries, or even countries. This for instance occurred in Ethiopia at the end of '90s after the Tendaho Geothermal Exploration Project during which a high number of Ethiopian geoscientists, engineers and technicians, belonging to EIGS, were trained and employed in field operations to drill and test 6 wells in the Dubti prospect. As the financing of the installation of a power plant exploiting the Dubti shallow reservoir failed, many of the skilled people left EIGS in the subsequent years. The capacity building achieved by EIGS within the Tendaho Geothermal Project was then substantially lost.

Let's now look at the personnel requirements estimated in 2015 for the same 9 countries. The estimate was performed by the companies and/or institutions in charge of the development of geothermal resources in their country. Estimates were of course linked to the plans for the execution of exploration and development projects as well on the installation of new power plants. The required staff at 2030 estimated for the 9 East Africa countries in terms of professionals and technicians is showed in **Figure 23** and **Figure 24**, respectively.

In practice, at the end of the 3 different periods lasting 5 years each, the required staff would amount to 2,943, 3,915 and 4,325, respectively (taking into account also the retirements). The analysis by type of professional skill showed the following required fractions to be covered within the following 15 years: 70% of geoscientists, 91% of reservoir engineers, 88% of drilling engineers, 84% of plant engineers. These results suggested a clear increasing need for geothermal Geoscientists, Engineers and Technicians across the region.

They also show a lower requirement for new geoscientists rather than for new drilling and reservoir engineers which could be justified by the fact that geoscientists constitute most of the present workforce in all countries but Kenya, in agreement with the stage of geothermal exploration in that countries. Geoscientists are mostly geologists and chemists which can also undergo a specialization stage on geothermal disciplines after the completion of the university degree, while drilling and reservoir engineers need to come for more specific university degrees, such as Petroleum Engineering. Petroleum engineers are often more attracted by the O&G industry because of higher international wages. Thus, filling the high estimated requirements for reservoir and drilling engineers will be for sure an issue. A bit easier should be to find plant engineers such as mechanical, electrical and process engineers.

Figure 23. Geothermal Workforce in 9 East Africa countries: required Technical Staff in 2030 in terms of geoscientist and engineers (Source: UNEP and ARGeo, 2015)

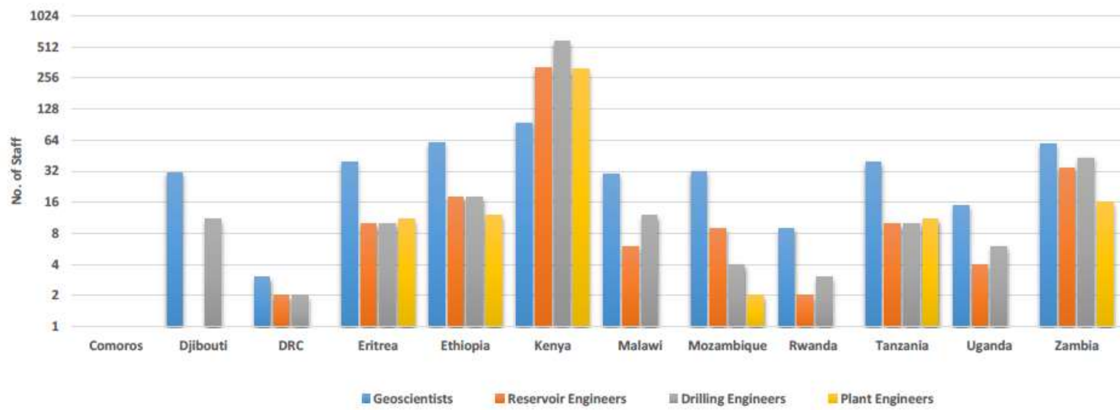
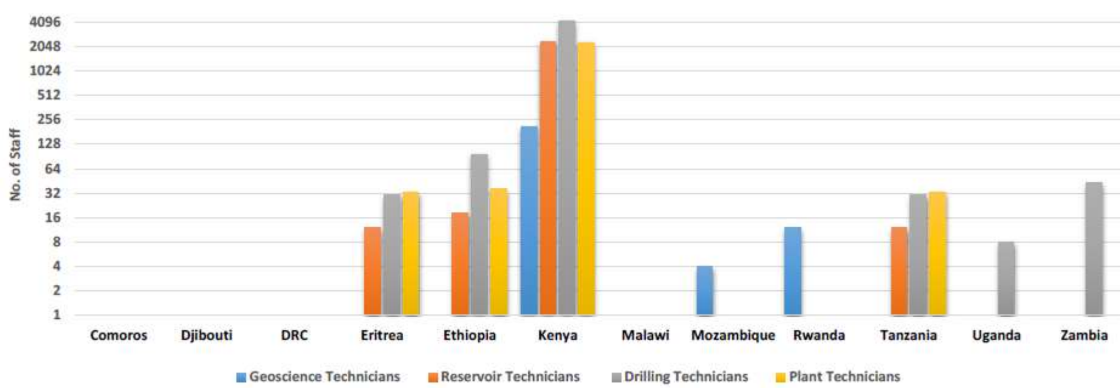
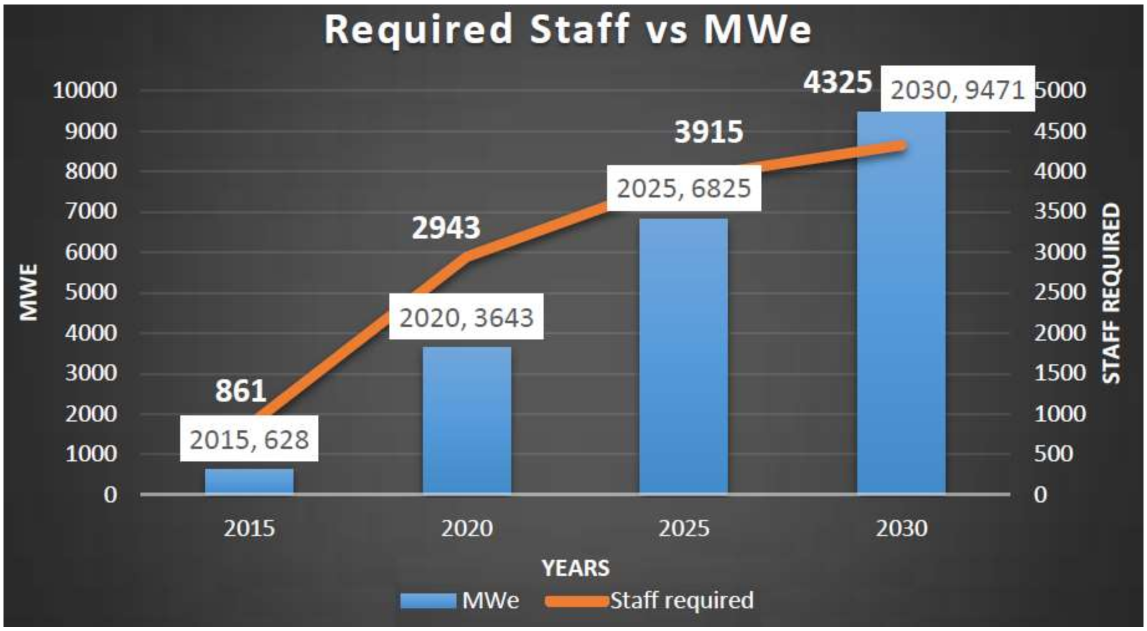


Figure 24. Geothermal Workforce in 9 East Africa countries: required Technical Staff in 2030 in terms of technicians (Source: UNEP and ARGeo, 2015)



The global survey results are shown in **Figure 25** where the installed power (MWe) and the required staff are plotted vs time at 5-year intervals. At 2030 a total installed power of 9,471 MWe was planned, requiring a total staff number of some 12,044 people. The biggest increment in staff requirement was estimated for the 2105-2020 period during which probably all the countries had concentrated the initial build-up of their workforce.

Figure 25. Estimated Geothermal staff requirements in East Africa countries from 2015 to 2030 (Source: UNEP and ARGeo, 2015)



These data refer to the survey made in 2015, and then they would need to be updated after 4 and half years. It can be observed that at the end of 2019 only Kenya was actually able to increase its installed power, while no new plants were in operation nor in construction in the remaining 8 countries. The actual installed power at the end of 2020 will likely be within 1,000 MW, indicating a gross overestimation of planned installed power. Consequently, it is then reasonable to conclude that actual staff requirements at the end of 2020 will be lower than those estimated by ARGeo in 2015.

Despite this possible overestimation, lack of skilled geothermal professionals and technicians is anyway a concrete issue for East Africa countries and as such was recognized by ARGeo and by the Governments. Thus, in order to address the challenge of technology transfer, toward the objective of fast tracking renewable energy projects, including geothermal resources for power generation and direct use applications, African countries planned to set up the Africa Geothermal Center of Excellence (AGCE) in order to build and strengthen their institutional and infrastructural capacities and create a critical mass of geothermal scientists and engineers in the continent. AGCE is intended to be a vehicle to ensure the development of skilled manpower and promotion of use of geothermal expertise in the continent in a sustainable manner.

AGCE has been established in 2017 (http://www.theargeo.org/AGCE/) as a joint effort with the Government of Kenya, The African Union, UNEP, ICEIDA, KenGen, GDC, BGR, UNU-GPT and Power Africa for support to geothermal development with a focus on capacity building.

The AGCE has been established in Kenya under the Kenyan law, and is using the existing training facilities of GDC and KenGen. Facilities includes among the others chemical, geophysical and well testing laboratories, drilling and power plant simulators. The AGCS is pursuing the following objectives:

- 1: Develop curriculum & Training Plans that can be re-used and customized to satisfy country-specific needs.

  Reduce member-country costs.

  Rapidly scale-up and maintain skilled geothermal workforce.

- 2: Provide access to shared specialized equipment, facilities, and technology.

  Avoid duplicated high upfront expenses.

  Share competencies and skills amongst member-countries.

- 3: Facilitate stakeholders' collaboration & knowledge sharing.

  Helps coordinate multiple donor agencies.

  Expands and builds data-base and knowledge-base.

Another important initiative of ARGeo is the organization of the African Rift Geothermal Conference which is held any two years in one of the East African Countries members of ARGeo. Next Conference, the 8th edition, is scheduled at UNEP headquarters in Nairobi, Kenya, from Oct. 26 to November 2020. The ARGeo Conference has become an important appointment for all institutions, companies and international stakeholders active of the development of geothermal resources in East Africa.

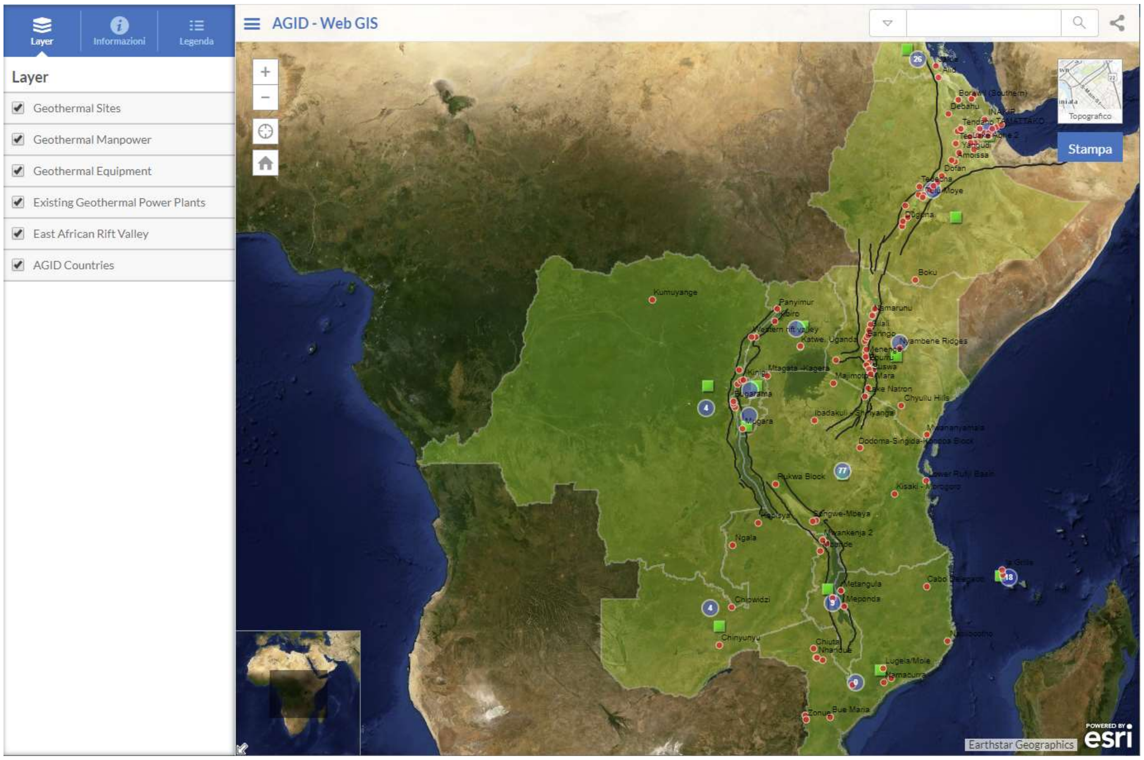
ARGeo is also managing the UN Environment Africa Geothermal Inventory Database (**AGID**). AGID (http://agid.theargeo.org/newagid/site/) is an information sharing platform and hub for geothermal related information in the East African Region. It aims at promoting the exploration, development and utilization of geothermal energy resources by storing, compiling, integrating of geothermal related information in the region and sharing it with end users - public and private entities. The objective of AGID is to catalyse geothermal investment in the region by providing geothermal related data and information to potential investors. Member countries of the initiative are: Eritrea, Djibouti, Ethiopia, D.R. of Congo, Uganda, Kenya, Rwanda, Burundi, Tanzania, Zambia, Malawi, Mozambique, Comoros.

The intended purposes and benefits of AGID are:

- Provide geothermal related data and information to potential investors.
- Create a Networking Platform and Hub for the East African Rift Region.
- Provide access to geothermal related information such as sites, reports, as well as human resource capacity and equipment available and required in the region.

The AGID Web GIS home page is shown in **Figure 26**. In addition to Web Gis options, a database for each of the Member countries is available, reporting about: the Organizations active on geothermal energy in the Country; list of Stakeholders; list of completed and on-going Programmes related to geothermal activities in the Country; list of Projects; list of geothermal sites, power plants, manpower, training initiatives; list of pertinent reports; list of available maps.

Figure 26. AGID Web Gis main page (Source: https://argeo.maps.arcgis.com/apps/PublicInformation/index.html?appid=e470068936ee42c2b68f6f09e02ef62c)



2.2 European Union (EU)

The **European Union (EU)** is a political and economic union of 26 member states that are located primarily in Europe. The EU has developed an internal single market through a standardised system of laws that apply in all member states in those matters where members have agreed to act as one. EU policies aim to ensure the free movement of people, goods, services and capital within the internal market, enact legislation in justice and home affairs and maintain common policies on trade, agriculture, fisheries and regional development. A monetary union was established in 1999, coming into full force in 2002, and is composed of 19 EU member states which use the euro currency.

EU recognized geothermal resource challenges and opportunities. The challenge is to allow widespread and cost-effective exploitation of geothermal resources in many different geological conditions. This can be achieved through enhanced geothermal systems that enable the exploitation of the Earth's heat where a reservoir of hot water and steam does not naturally exist.

There are other, so called unconventional resources, in particular very hot (supercritical) resources, that, if tapped, could enormously increase the amount of electricity produced per well. This would greatly reduce the costs of the electricity produced.

What the European Commission is doing. The European Commission supports research and development in geothermal technologies, funding research projects on both direct use of heat and the use of extracted heat for electricity generation. EU support also focuses on reducing costs in exploration and drilling because geothermal installations have high capital costs.

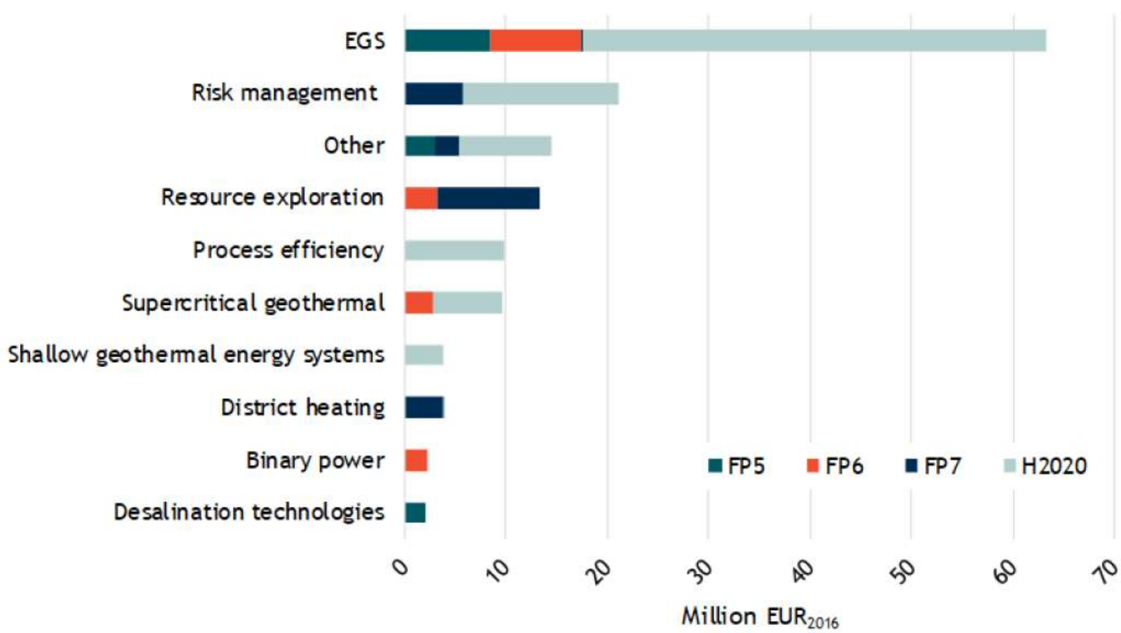
Funding, and per program funding, of geothermal development by EU has increased considerably (Trinomics, 2018). The major increase in funding has been experienced for the H2020 programme, as shown in
Table *2*.

Table 2. EU funding and number of projects per Framework Programme (funding in million euros) Source: Cordis, 2018 (Source: Trinomics, 2018)

Framework programme	Period	EU funding	No. of projects
FP5	1998-2002	13.64	11
FP6	2002-2006	17.35	5
FP7	2007-2013	22.12	6
H2020	2014-2020 *(data available up to mid-March 2018)*	90.80	15
Total EU funding		143.91	37

As far as the funding per sub technology is concerned, EGS (Enhanced Geothermal Systems) has been the primary focus area, with Risk management gaining importance in FP7 and H2020, as shown in **Figure 27**. A recent shift away from resource exploration towards operations has also been observed. The focus on EGS was originally driven by the initial EU engagement in the '70s on the funding of Soultz sous Forêts hot dry rock project located in France, close to the German border. While conventional hydrothermal reservoirs are only found in particular geodynamic and geological environments, the exploitation of the heat contained in hot rocks found at sufficient high depth can in principle be performed almost anywhere. This is the reason for the present high fraction of EU funds spent on EGS R&D projects within EU countries.

Figure 27. EU funding per sub technology. Source: Cordis, 2018 (Source: Trinomics, 2018)



The analysis of EU funding historical data made by Trinomics (2018) pointed out the following conclusions:

- In early Framework Programs, EU funding helped establish the foundations for a future geothermal R&D agenda through the FP6 ENGINE project. ENGINE set clear definitions for EGS, and took stock of current best practices.
- EU funding has significantly helped to improve the appraisal of geothermal systems, enabling more accurate placing of wells and ultimately reducing the financial risk of geothermal projects. FP7 IMAGE is a clear example of that.
- EU funding has facilitated the implementation of high risk, high reward deep geothermal projects, such as the successful H2020 DESCRAMBLE project dealing with the exploration for supercritical resources in the Larderello field (Italy).
- H2020 projects have exceptionally high levels of industrial participation, fostering public private partnerships in technology and knowledge development. SURE, GEOWELL and GEMex focus on improved productivity and operational risk reduction.

The **European Technology & Innovation Platform on Deep Geothermal (ETIP-DG)** (https://www.etip-dg.eu/) is an open stakeholder group, endorsed by the European Commission under the Strategic Energy Technology Plan (SET-Plan), with the overarching objective to enable deep geothermal technology to proliferate and reach its full potential everywhere in Europe. The primary objective is overall cost reduction, including social, environmental, and technological costs.

It brings together representatives from industry, academia, research centres, and sectoral associations, covering the entire deep geothermal energy exploration, production, and utilization value chain. The Platform was launched in March 2016 during a Geothermal Forum of stakeholders, including large companies, SMEs, academia and research institutions. The European Technology and Innovation Platforms (ETIPs) have been recognised by the European Commission as a tool to strengthen cooperation with Stakeholders under the Strategic Energy Technology Plan (SET-Plan), as part of the H2020 programme.

The ETIP-DG actively collaborates with the European Technology and Innovation Platform on Renewable Heating & Cooling (RHC-Platform), which gathers stakeholders from the biomass, geothermal and solar thermal sector to define a common strategy for increasing the use of renewable energy technologies for heating and cooling. The primary objective is overall cost reduction, including social, environmental, and technological costs.

Activities of ETIP-DG are:

- The development of a long-term common Vision for deep geothermal for power and/or heat.
- The development of a European Strategic Research Agenda for deep geothermal for the next decade(s).
- Recommendations for the implementation of the strategic research agenda through a customized Technology Roadmap.
- Contribution to the European industry and research to maintain and consolidate its leading position in energy technologies for geothermal.
- The definition of the needs of RD&I activities covers the development of all deep geothermal technologies.

Activities are performed by 5 Working Groups:

- Exploration. Reducing exploration costs, developing new techniques, improving exploration of geothermal resources to decrease the geological risk.
- Deep drilling. Reducing costs with novel drilling concepts and improvements to current drilling technology, optimising the economics of drilling operations.

- Production technologies. Increasing reservoir performance, developing new materials and equipment to optimize the efficiency and decrease costs.
- Surface systems / Generation. Improving the overall conversion efficiency, addressing the needs for flexibility in the integrated energy system.
- Non-technical. Improving the RD&I framework, supporting market deployment, promoting social and environmental sustainability.

ETIP-DG also manages the European Geothermal RD&I Document Search Engine (EGRISE) (https://www.etip-dg.eu/geothermal-research-search-engine/).

GeoElec (http://www.geoelec.eu/) website is a hub of information about geothermal electricity in Europe. It began as the website for the GeoElec project, (2011-2013) and is now maintained by the European Geothermal Energy Council. GeoElec project produced an action plan towards more geothermal electricity generation in Europe, with the objective of doubling the installed geothermal power capacity in Europe by 2020. The project also looked at concrete actions to reach these objectives, for example conditions for financial feasibility, regulatory frameworks, and public acceptance. Available resources are related to the following topics: Resource assessment; Financing; Regulations & Environment; Training & Employment; Communication; Research & Development.

The **Joint Research Centre** (**JRC**) (https://ec.europa.eu/jrc/en) has released at the end of 2018 the Geothermal Power Plant Dataset of worldwide geothermal power plants including technological details (e.g. nameplate and running capacity, turbine type). The dataset is updated to the end of 2017. Within the Low Carbon Energy Observatory, an Administrative Arrangement being executed by DG-JRC for DG-RTD, JRC has published a technology and a development market report on geothermal energy (JRC, 2019a; 2019b). JRC has also published a Geothermal Energy Status Report in 2014 and 2015 (Sigfússon and Uihlein, 2014; 2015) focused on technology, market and economic aspects of geothermal energy in Europe.

2.2.1 European Investment Bank (EIB)

The European Investment Bank (EIB) (https://www.eib.org/en/index.htm), the long-term lending institution of the European Union, whose shareholders are the 26 European Union member states, has been active across Africa for over 55 years. EIB activities follow policies and objectives set down by European Union member states and whose Finance Ministers are the EIB’s Governors.

Energy is a key EU policy and the EIB helps foster the investment needed for energy market transformation. In late 2019, EIB approved a new energy lending policy and confirmed the EIB’s increased ambition in climate action and environmental sustainability, by transforming energy systems rapidly in order to achieve net-zero emissions and to minimise human impact on climate.

In line with its new energy lending policy, the EIB will no longer consider new financing for unabated, fossil fuel energy projects, including natural gas. With this decision, the EIB has become the first international finance institution to end financing for fossil fuel projects and to focus its support on projects that are fully aligned with the Paris Agreement. In 2019, EIB loans helped to construct approximately 30,400 km of power lines and install power plants for 13,177 MW, of which more than 98% were based on renewable energy sources.

The EIB has had a permanent office in Nairobi, responsible for the East and Central Africa region since 2005. EIB restated its firm commitment to support infrastructure and private sector growth in East Africa. EIB has contributed to the development of energy sector in the region, including the development of installed power at Olkaria geothermal field and to the interconnection of Olkaria power plants to the national electric grid. The following projects have been funded by EIB for the development of the Olkaria geothermal field in Kenya:

- OLKARIA GEOTHERMAL POWER

Amount EUR 9,000,000, Signature date 20/12/1982

- KPLC - OLKARIA II (KENYA). Construction of new geothermal power station with associated transmission lines and substations in Nairobi.

  Amount EUR 41,000,000, Signature date 15/12/1999

- OLKARIA II EXTENSION. Expansion of Olkaria II geothermal power plant (Rift Valley).

  Amount EUR 38,027,679, Signature date(s) 31/05/2005 & 19/11/2009

- OLKARIA I & IV GEOTHERMAL EXTENSION. Expansion of Olkaria I and construction of Olkaria IV power plants to increase power generation capacity of Olkaria geothermal steam field.

  Amount EUR 119,000,000, Signature date 15/12/2010

- OLKARIA I GEOTHERMAL EXTENSION

  Amount EUR 72,000,000, Signature date) 04/09/2017

2.2.2 European Geothermal Energy Council (EGEC)

EGEC (https://www.egec.org/), the **European Geothermal Energy Council**, is a non-profit international organisation founded in 1998 to promote the European geothermal industry and enable its development both in Europe and worldwide, by shaping policy, improving business condition, and driving more research and development. Based in Brussels, EGEC works with its members on policy, market intelligence, and communication, providing a link between the industry and European institutions. More than 120 members from 28 countries, including developers, equipment manufacturers, electricity providers, national associations, consultants, research centres, geological surveys, and public authorities, make EGEC a unique network, uniting and representing the entire European geothermal sector.

EGEC mission and vision is summarized as follows:

- A sound policy framework and financial instruments which allow geothermal energy to compete with traditional sources;
- Increased research and development;
- The development of the geothermal industry inside and outside of Europe.

EGEC organizes any 3 years the European Geothermal Congress (EGC), an event allowing to present and discuss new developments in the science, technology, industry, and policy of geothermal energy.

2.3 African Union (AU)

The African Union (AU) (www.au.int/en) is a continental body consisting of the 55 member states that make up the countries of the African Continent. It was officially launched in 2002 as a successor to the Organisation of African Unity (OAU, 1963-1999). The African Union (AU) was launched in July 2002 in Durban, South Africa, following a decision in September 1999 by its predecessor, to create a new continental organisation to build on its work. The decision to re-launch Africa's pan-African organisation was the outcome of a consensus by African leaders that in order to realise Africa's potential, there was a need to refocus attention from the fight for decolonisation and ridding the continent of apartheid, which had been the focus of the OAU, towards increased cooperation and integration of African states to drive Africa's growth and economic development.

The AU is guided by its vision of "An Integrated, Prosperous and Peaceful Africa, driven by its own citizens and representing a dynamic force in the global arena." The work of the AU is implemented through several principal decision-making organs: The Assembly of Heads of State and Government, the Executive Council, the Permanent Representatives Committee (PRC), Specialised Technical Committees (STCs), the Peace and Security Council and The African Union Commission.

The African Union Commission (AUC) is the AU's secretariat and undertakes the day to day activities of the Union. It is based in Addis Ababa, Ethiopia. AUC is structured in several department including the Energy Department. The main objective of the Energy Development Strategies and Initiatives of AUC in Africa is to increase energy access to the African people, improve livelihoods and to ensure environmental sustainability. Among the initiative of the Energy department there is the implementation of the **Regional Geothermal Programme** (RGP) initiated in 2009 and the **Geothermal Risk Mitigation Facility**.

The Ministers of Energy of ten African countries of the East African Rift System (EARS) and their representatives recommended the launch by AUC of the RGP for promoting the exploration, development and utilization of the regions extensive geothermal resources. For this purpose, AUC established the RGP Working Group and the RGP Coordination Unit in its Energy Department to support these activities. AUC has the mandate to create a regional forum where the countries will participate in order to institutionalize their involvement in the activities of the proposed geothermal structure and to promote the regional project for implementation in the different countries according to their needs. The project includes field activities in order to identify promising resource areas, capacity building to ensure the sustainable and full exploitation of the geothermal resources, and the cultivation of public awareness about the utility of the energy resource.
One of the important accomplishments of the RGP is the publication of The African Union Code of Practice for Geothermal Drilling (AU, 2016) in collaboration with BGR and with the support of the Gov. of New Zealand which made available the New Zealand Code of Practice. The Code should be implemented into the national regulations of the 11 member states of the AU Geothermal Risk Mitigation facility (GRMF).

The code is intended to promote best practice in the management of deep geothermal wells throughout their lifetime from drilling to abandonment of wells. It provides guidance and encourages operators, drilling contractors, service companies, regulators, and other stakeholders to improve the overall management of wells, including safety and environmental management. The Code also helps ensure that all relevant technical and scientific data that can and should be obtained during all drilling operations is collected and made available to the appropriate governmental entity of the country in which the drilling takes place.

2.3.1 GRMF (Geothermal Risk Mitigation Facility)

The African Union Commission (AUC) on the one side and the German Federal Ministry for Economic Cooperation and Development (BMZ) and the EU-Africa Infrastructure Trust Fund (EU ITF) via KfW Entwicklungsbank (KfW) on the other side established the Geothermal Risk Mitigation Facility (GRMF) (https://grmf-eastafrica.org/) to fund geothermal development in Eastern Africa. In addition, the UK Department for International Development (DFID) is making a contribution to the GRMF.

The GRMF was established to fund, facilitate, and accelerate geothermal development in Eastern Africa. The overall objective of the GRMF is to encourage public and private sector investment into geothermal power generation. The GRMF therefore acts as a catalyst in establishing geothermal energy as a strategic option for power generation capacity expansion in eleven partner countries in the Eastern African Rift region, namely: Eritrea, Djibouti, Ethiopia, Kenya, Uganda, DR of Congo, Rwanda, Burundi, Tanzania, Comoros, Zambia. Somalia is already an eligible country and will be soon accepted as a member country. Contacts are underway with Zimbabwe and Madagascar, but no written application has been presented till now.

The programme co-finances surface studies and drilling programmes aimed at developing geothermal energy projects – being a largely untapped indigenous and renewable energy resource. The GRMF programme comprises approx. 122 million USD available for funding, to be updated depending on further decisions by the GRMF donors.

The GRMF was launched in April 2012 and is implemented in a series of application rounds. The 5th Application Round was completed in October 2018. **Figure 28** shows the location of awarded projects from 1st to 5th Application Round with the distinction between Surfaces Studies and Drilling Programmes. It is clear that most of the awarded projects are located in Ethiopia and Kenya, followed by a few projects in Uganda and Tanzania and just one project in both Djibouti and Comoros.

Figure 28. Awarded projects from Application Round 1 to Application Round 5 of GRMF: status at November 2018 (Source: GRMF, 2018a)

Focused on the reduction of geothermal exploration risks, GRMF is funding Surface Exploration studies and Drilling Programmes related to either slim holes or full diameter exploration wells, including the costs for infrastructures and well testing.

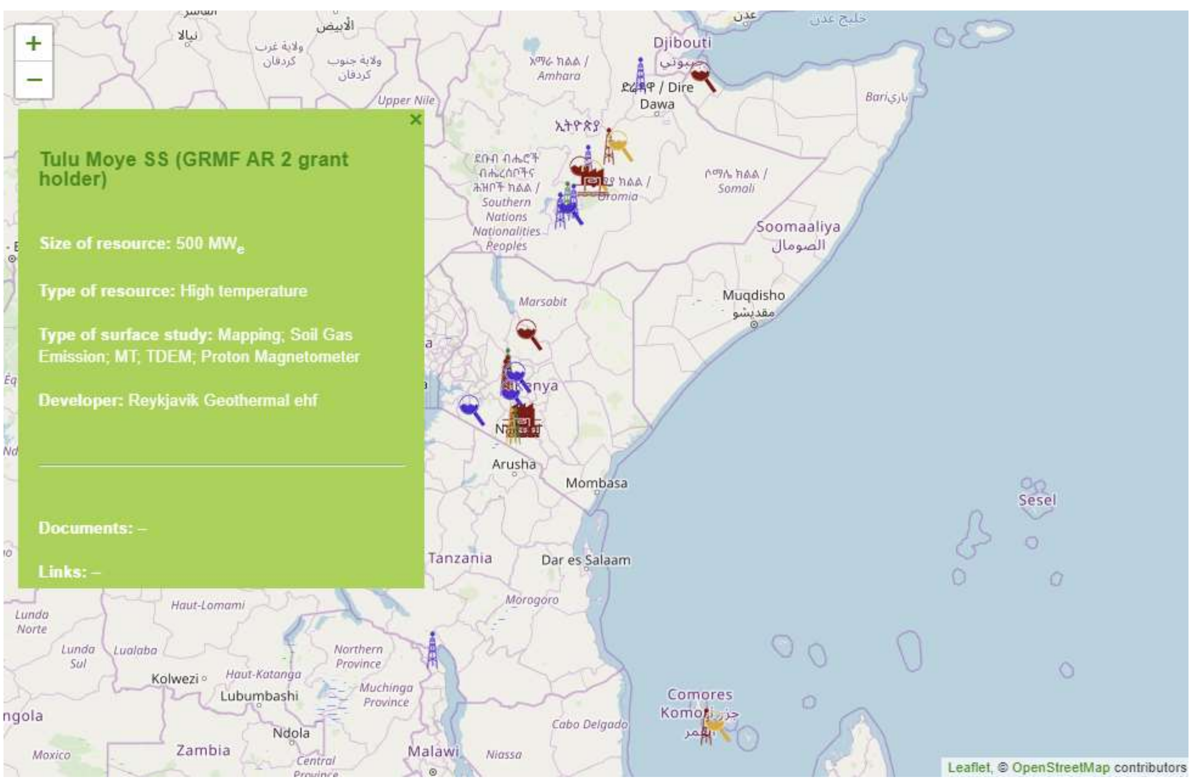
In 2018 the Oversight Committee launched an online survey to 29 developers that applied in total for 64 projects (27 drilling programs, and 36 surface studies) in eight different countries between 2013 and 2018, in the course of five application rounds (GRMF, 2018b). Until now, 16 drilling projects and 14 surface studies have received GRMF grants. The objective of the survey was to get an insight into the market, as well as to detect barriers and obstacles which impede the development of geothermal power projects in the region. Survey results are documented in the report "GRMF Developer Survey 2018" (GRMF, 2018b).

The 6th Application Round has been launched on May 6, 2020, with a kick-off webinar held in substitution to the planned meeting to be held at the 2020 World Geothermal Congress cancelled due to the COVID-19 pandemic. The deadline for the Expression of Interests (EOI) is July 15, 2020.

The GRMF is a very important initiative aimed at reducing one of the main constraints to the development of geothermal energy, i.e. the reduction of exploration costs and associated financial risks related to the mining nature of geothermal energy.

The GRMF Web GIS (https://grmf-eastafrica.org/web-gis/) is providing information about the geothermal activities in East Africa. Different "Display Options" allow to see the location of geothermal power plants, GRMF funded surface studies and GRMF funded drilling projects on the map. Clicking on one of the countries in the "Country Facts" list allows to find information on the total geothermal installed capacity, and at the same time to zoom to the country on the map. Clicking on one of the symbols displayed on the map, an information box with details on the respective item appears (see **Figure 29**).

Figure 29. GRMF WebGis page. Example of the information box related to the Tulu Moye drilling project, Ethiopia (Source: https://grmf-eastafrica.org/web-gis/)



2.4 Nordic Development Fund (NDF)

The NDF (http://www.ndf.fi/) is the joint development finance institution of the five Nordic countries i.e. Denmark, Finland, Iceland, Norway and Sweden. NDF was established in

November 1988 and commenced operations in February 1989. The objective of NDF's operations is to facilitate climate change investments, primarily in low-income countries. NDF finances projects usually in cooperation with bilateral, multilateral and other development institutions. The operations mirror the Nordic countries' priorities in the areas of climate change and development. NDF flexibly uses grants, loans, equity and any combination of these as financing instruments. NDF's capital is provided from the development cooperation budgets of the five Nordic countries. The original subscribed and paid-in capital by the Nordic countries is equivalent to approximately EUR 1 billion. NDF's headquarters is located in Helsinki, Finland.

NDF provides grant financing for interventions targeting adaptation to and mitigation of climate change in low-income countries. Climate change mitigation measures are targeted at reducing greenhouse gas emissions by improved energy efficiency, increased use of renewable energy sources, carbon sequestration, sustainable transport initiatives, enhanced waste management and sewage treatment.
NDF supports projects:

- addressing the mitigation of climate change;
- supporting the adaptation to climate change;
- related to infrastructure, natural resources and capacity building
- through grant financing;
- in low-income countries in Africa, Asia and Latin America;
- in cooperation with multilateral and bilateral development institutions.

NDF co-finances climate change initiatives in Africa, Asia and Latin America. Such funding generates opportunities for both the Nordic and the global business community. NDF will normally finance a component of a larger programme or project and the responsibility for procurement and contract negotiations rests with the national authorities. Projects have a national executing agency, and in relation to NDF, a lead agency. The lead agency can be the World Bank Group, Asian Development Bank, Inter-American Development Bank, African Development Bank or other agencies engaged in development financing.

NDF has a two-stage approval process. Projects are first approved for the pipeline and then they receive final approval from the NDF Board of Directors. Projects in the pipeline are subject to change and may not necessarily be presented for final approval. Examples of projects focused on geothermal resources in East Africa are:

- Karisimbi Geothermal Prospect [NDF C3 C8]. Rwanda, 2011-2013. Nordic Partner: Reykjavik Geothermal Ltd. (Iceland). The objective was to pave the way in Rwanda for the provision of geothermal energy, an indigenous clean renewable low-cost energy, either in the form of electricity or direct applications such as heat and cooling.
- Regional Africa Geothermal Exploration [NDF C48]. 2013-2017. Partner Agency: ICEIDA. The project assisted East Africa Rift Valley States (EARS) countries in completing the exploratory phase of geothermal development.
- Training in Geothermal Drilling Operations [NDF C41]. Kenya, 2012-2015. Partner Agency: World Bank. The main objective was to accelerate the development of Kenya's geothermal resources by taking the already available and incoming drilling equipment to efficient use.
- Training needs assessment, Geothermal drilling training [NDF C41]. Kenya, 2016. Consultancy services for a training on geothermal drilling operations.
- Geothermal Surface Exploration and Training in Gedemsa, Ethiopia [NDF C48]. Surface exploration studies conducted in a priority site in Ethiopia.

- Surface exploration and training in Luhoi, in Rufiji, and Kiejo-Mbaka geothermal areas in Tanzania. 2016-2017, [NDF C48].
- Consultancy Services for Mid-Term Review of the Regional Geothermal Project in East Africa, 2015 [NDF C48].
- Review of the Conceptual Model of Suswa Geothermal Prospect, Kenya. 2015.
- Feasibility study and Preparation of a Concept Note for an African Geothermal Centre of Excellence, 2014.
- Geothermal Surface Exploration in Aluto Langano, Ethiopia, 2014 [NDF C48].
- Geothermal Surface Exploration in Tendaho Alalobeda, Ethiopia. 2013 [NDF C48].

2.5 Icelandic Ministry of Foreign Affairs (MFA)

The Ministry of Foreign Affairs (MFA) of Iceland (https://www.government.is/ministries/ministry-for-foreign-affairs/) safeguards the interests of Icelandic citizens, companies and consumers by facilitating access to international markets and strengthening free trade. The Ministry supports Icelandic firms abroad and promotes Icelandic arts and culture. The Foreign Ministry conducts Iceland's political relations with other states and international organisations, covering a wide range of issues ranging from human rights to security and defence, and trade. Iceland's international development cooperation aims to deliver measurable results in poverty eradication, improving living conditions and achieving gender equality, freedom and prosperity in the world.

Thanks to the extensive experience gained by Icelandic firms and institutions in exploring and developing the large geothermal resources of the country, international development cooperation of MFA has been long focused on providing technical assistance to foreign countries both directly and in collaboration with other international institutions. Till 2017 the operating harm of MFA was the **Icelandic International Development Agency** (**ICEIDA**).

One of the major projects in East Africa was the **GEP** (**Geothermal Exploration Project**) jointly funded by the Ministry for Foreign Affairs of Iceland and the Nordic Development Fund (NDF) with a total budget of € 10 million, whose implementation started in 2013. The project was implemented in collaboration with several partners including UN Environment and the World Bank and included collaboration with the African Union, whose Commission is responsible for donor coordination and manages the Geothermal Risk Mitigation Facility (GRMF).

The main objective of the GEP was to assist countries in the EARS to increase their knowledge of geothermal potential by conducting reconnaissance and surface exploration studies and to build capacity and expertise in the field of geothermal development and utilization (GOPA, 2019). The project aimed to assist countries to have:

- a realistic assessment of potential geothermal sites;
- plans for further action, where applicable, with drilling targets identified;
- capacity to move forward based on those plans and submit exploration drilling projects into funding pipelines.

The specific objective of the project was to enhance geothermal knowledge and capacity that enables further actions on geothermal utilization in EARS countries.

In preparation of the GEP, the following potential participating countries were identified, albeit at different stages of exploration and implementation of their geothermal resources: Burundi, Comoros, Djibouti, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda and Zambia.

National Stakeholders in the main partner countries were:

- Djibouti: Djibouti Office for Geothermal Energy Development (ODDEG).
- Ethiopia: Geological Survey of Ethiopia (GSE); Ethiopian Electric Power (EEP).
- Kenya: Geothermal Development Company (GDC); African Geothermal Centre of Excellence (AGCE).
- Tanzania: Tanzania Geothermal Development Company (TGDC).

The following projects were financed:

- Eritrea: Prefeasibility Study of the Alid Geothermal Prospect. Phase 1: Geologic, geochemical and geophysical surveys. Phase 2: combined transient electromagnetics (TEM) and magnetotellurics (MT) survey; hydrogeological survey; study of the possible social and environmental impact of geothermal development at Alid.
- Djibouti: Capacity Building and Technical Assistance for Geothermal Development in Djibouti implemented by the Djiboutian Office for Geothermal Energy Development (ODDEG). The immediate objective of the project was the improved knowledge and skills for ODDEG staff on geothermal surface exploration and management of geothermal projects, in order to enable further actions on geothermal energy development in Djibouti. The project included surface explorations and training in the areas of Lake Asal and Lake Abhé which led to the identification of drilling sites.
- Ethiopia: The focus of the project was to address the needs for Geological Survey of Ethiopia (GSE) and Ethiopian Electric Power (EEP) to i) build capacity to handle further growth and development in geothermal energy production, and ii) assist with finalizing geothermal surface explorations and associated geophysical and geochemical studies in order to identify locations for drilling of exploration and production wells in target sites. The project included surface explorations and training in the areas of Aluto-Langano and Tendaho-Alalobad which led to the identification of drilling sites.
- Kenya: Capacity building support agreement with Kenya's Geothermal Development Company (GDC). In addition to capacity building of GDC staff, the project included the technical review of the surface exploration studies for the Suswa prospect conducted with revised conceptual model and identified drilling targets.
- Rwanda: Agreement with the Energy, Water and Sanitation Authority (EWSA) in Rwanda to support Capacity Building and Technical Assistance for Geothermal Drilling. In addition to capacity building, an Environmental and Social Impact Assessment was conducted for the Karisimbi Geothermal Project.
- Tanzania: Agreement with Tanzania Geothermal Development Company Limited (TGDC) (under the Ministry of Energy and Minerals) for the Surface Exploration and Capacity Building for Geothermal Development in Tanzania. The project included: i) Surface exploration and identification of up to 3 drilling targets, if geothermal potential allows, in the Luhoi geothermal prospect; ii) training in surface exploration in Kiejo-Mbaka geothermal area; iii) Technical Assistance for TGDC to support the advancement of the development of the Ngozi geothermal prospect.
- Malawi: technical assistance for the geothermal reconnaissance and exploration project launched by the Ministry of Natural Resources, Energy and Mining (MoNREM) of Malawi.

2.6 Agence Française de Développement (AFD)

The Agence Française de Développement (AFD) Group (https://www.afd.fr/en) funds, supports and accelerates the transition to a fairer and more sustainable world. Focusing on climate, biodiversity, peace, education, urban development, health and governance, AFD teams carried out more than 4,000 projects in France's overseas departments and territories and another 115 countries. In this way, AFD contributes to the commitment of France and French people to support the Sustainable Development Goals (SDGs).

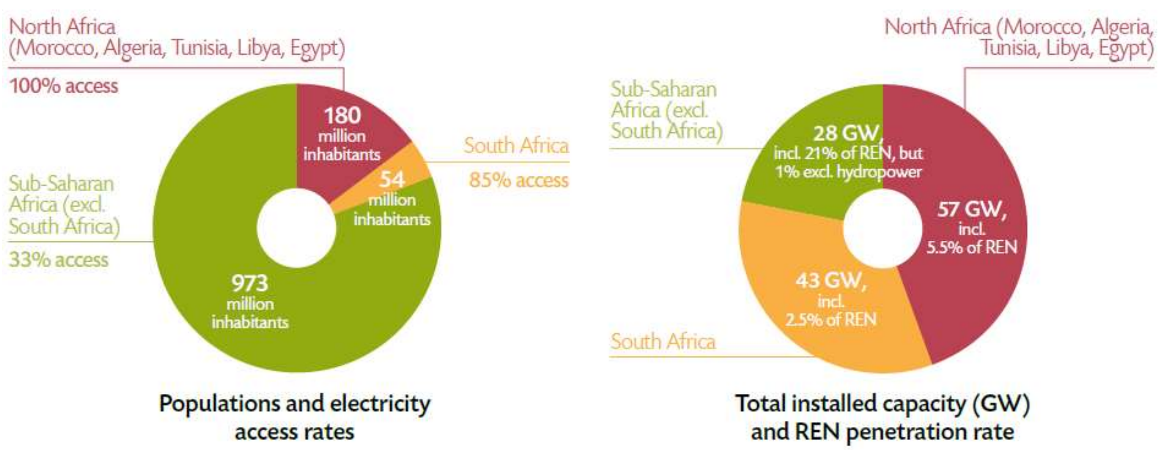
AFD strategy rests on a vision of "world in common" and five foundational commitments that underpin all actions: 100% Paris Agreement, 100% social link, 3D development thinking (Défense, Diplomacy and Development), non-sovereign first and partnership design.

100% PARIS AGREEMENT. The Paris Agreement now stands at the heart of the AFD Group mandate. The Agency will draw on public and private resources to fund capital investments that protect the Earth from climate change and biodiversity loss: all project funding will finance resilient low-carbon development in keeping with the Paris Agreement.

AFD is committed to speed an energy transition towards a more sustainable, resilient and inclusive model in Africa (AFD, 2016). In 2014, Africa accounted for 16% of the world's population, less than 6% of energy consumption and 3% of greenhouse gas emissions. With an average annual economic growth rate of 4.5% over the past five years, Africa is experiencing increasing demand for energy and a significant need for infrastructure to meet this demand. The continent has huge untapped renewable energy potential to achieve this (hydropower, geothermal, biomass, solar and wind energy).

Sub-Saharan Africa is also faced with a marked energy divide: over 65% of the population still does not have access to an electricity service (see **Figure 30**) and over 80% uses traditional fuels (wood, charcoal) for cooking. Various energy solutions can be considered to address this: extend and increase the density of grids, or decentralized solutions, in which renewable energies have an important role to play. In this context, Africa's energy transition will combine the development of its renewable energy potential and the development of access for all. This will result in a low-carbon growth path.

Figure 30. *Populations and electricity access rates (left) and Total installed capacity (GW) and Renewables penetration rate (right) in Africa (Source:* AFD, 2016*)*



While Africa has substantial potential for renewable energy generation (excluding large-scale hydropower), it still remains marginal in the energy mix. Yet in comparison with imported fossil fuels, which are costly and volatile, renewable energies today offer competitive solutions. According to AFD, the obstacles to their development in Africa are:

- Institutional: investors need to minimize transaction costs and secure the purchase of electricity produced over the long term;
- Financial: although the investment cost is offset by the extremely low operating costs, it is deemed to be high;

- Technical: the transmission and distribution grids, especially the control-command systems, are often unsuitable for absorbing intermittent energy sources.

AFD works to remove these obstacles by proposing: support for strengthening regulatory frameworks, long-term concessional loans, and the integration of “smart grid” components in projects. According to AFD’s energy strategy in Africa, the types of project financed are related to i) Sustainable energy, ii) Secure energy, iii) Accessible energy. The funded projects in Africa till 2016 (AFD, 2016) are shown in **Figure 31**. Geothermal projects have been financed by AFD in Djibouti, Ethiopia and Kenya. A brief projects summary is given here below.

Olkaria I And IV Geothermal Power Stations, Kenya (start date Dec. 15, 2010). The € 86 M project was co-financed by AFD with the European Investment Bank (EIB), JICA, KfW, and the World Bank.

The project was aimed to: install two new 70 MW turbines at the Olkaria I site; install two 70 MW turbines at the Olkaria IV site; use the existing 45 MW at Olkaria I with steam from Olkaria II site. This operation was a pilot project for the Mutual Recognition of Procedure initiative aimed at improving efficiency by pooling the resources of European financial institutions. AFD played leadership role among European donors.

The project has added 280 MW to KenGen generating capacity in Kenya, increasing the installed base capacity by almost 15%. This helped to support the legitimate growth of the country's energy consumption. Beyond economic growth, this increase in demand was also driven by the increase in connection rate, as at the time only 30% of Kenyan households had access to the electricity network; enhanced national resource (geothermal heat), the cost of which is very competitive and which also has the advantage of being renewable and enabling continuous electricity production (base load); promote Kenyan growth in low carbon through the development of clean energy.

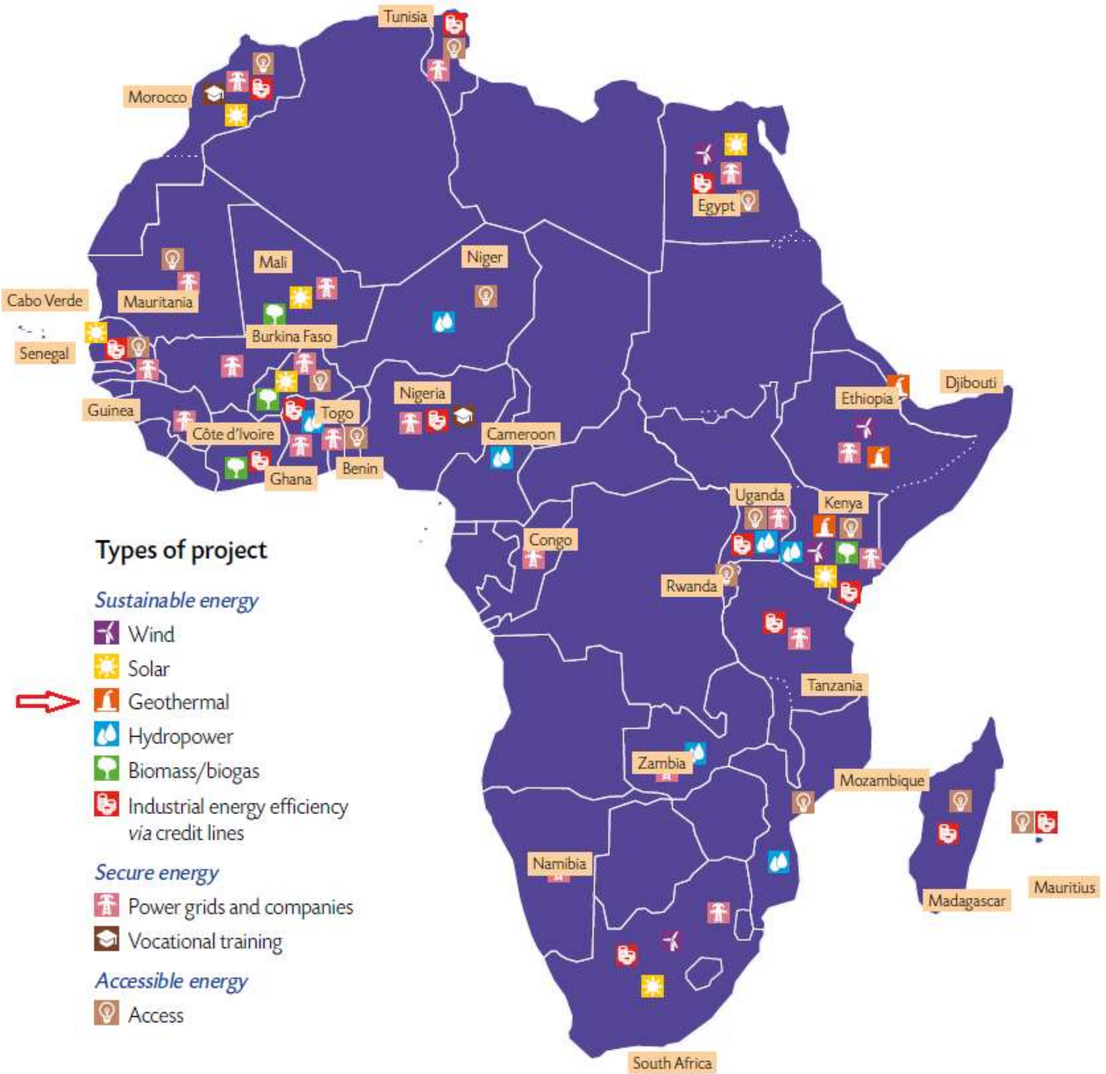
Support for geothermal exploration in Menengai, Kenya (start date Apr. 5, 2011). The € 56 million project financed two components:

- Support for the achievement of a master plan highlighting the potential of renewable energies;
- Support to the Geothermal Development Company (GDC) with institutional support and the purchase of two drilling rigs.

This funding supported the development of renewable energy in Kenya by:

- Contributing to the financing of geothermal exploration for the development of a 400 MW geothermal resource in Menengai and in future sites developed by GDC;
- Providing better understanding of renewable generation potential in Kenya;
- Improving planning tools and promoting better integration of renewable energies.

Figure 31. AFD's energy strategy: projects financed in Africa. They include geothermal projects in Djibouti, Ethiopia and Kenya (Source: AFD, 2016)



Supporting geothermal development in the Tendaho region in Afar, **Ethiopia** (start date Apr. 7, 2015). In July 2014, a 9 M euro concessional loan (AFD) combined with a 7.5 M euro grant from EU-Africa Infrastructure Trust Fund (ITF) were allocated to the Ethiopian Government, in order to develop the geothermal resource in the Dubti prospect (Tendaho graben).

The Tendaho Area — a volcanic region located in the south of the Afar — has witnessed the advanced geological exploration and deep exploratory drilling from the end of '70s to mid '90s. The project aims to bring a conclusion to these activities, in order to make available an exploitable resource. The Ethiopian Electric Power (EEP) and the Geological Survey of Ethiopia (GSE) have set two objectives for the development of the field, whose specificity lies in the coexistence of an already discovered shallow reservoir and a deep inferred reservoir:

1. The delineation and the development of the shallow reservoir (about 600m deep) in order to allow a sustainable exploitation with an estimated capacity of 10MW;

2. The exploration of the deep inferred reservoir (up to 2,500 m deep) by drilling deep wells.

The aim of the project is to support the Ethiopian economic growth by developing geothermal energy (a source that is reliable and low-carbon) and thereby to improve its capacity for climate change adaptation.

Given Ethiopia's dependency on hydropower, the diversification of energy sources will help the country to adapt to climate change — even if these geothermal resources will be developed later on (medium-term). The project, aiming to meet the domestic and regional demand, will also contribute to the Ethiopian economic growth by developing a new power generation capacity in the medium-term.

Djibouti Geothermal Exploration Project. The project is being led by Electricity of Djibouti (EDD) and is co-financed by AFD, the World Bank, African Development Bank and a number of other partners (OFID, GEF, ESMAP and the Government of Djibouti). This project marks AFD's return to the energy sector in Djibouti. It will result in better access to electricity for the population and provide a unique asset to boost the country's economic development.

The project aims at exploring the Fialé caldera, in the Asal Rift region in the centre of the country. The drilling operations were launched on July 11, 2018. The geothermal capacity of the site is to be assessed by drilling three directional boreholes at a depth of 2,500 m in a reservoir of fractured volcanic rocks where the water temperature is estimated at 300 °C. This will make it possible to determine the commercial viability of the resource, with the aim of installing the first geothermal power plant in Djibouti.

2.7 African Development Bank (AfDB)

The overarching objective of the African Development Bank (AfDB) Group (https://www.afdb.org/en) is to spur sustainable economic development and social progress in its Regional Member Countries (RMCs), thus contributing to poverty reduction. The Bank Group achieves this objective by:

- mobilizing and allocating resources for investment in RMCs;
- providing policy advice and technical assistance to support development efforts.

In 2015, AfDB agreed together with many other multilateral development institutions on a same set of objectives, called the Sustainable Development Goals. Those having a possible impact on the geothermal resources development in East Africa are the following ones:

- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all.
- Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
- Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
- Goal 13. Take urgent action to combat climate change and its impacts.

The current AfDB Strategy for 2013–2022 is firmly rooted in a deep understanding and experience of how far Africa has come in the last decade, and where it wishes to go to in the next one. Africa has embarked on a process of economic transformation with solid and sustained growth over a decade, but it has been uneven and without a sufficiently firm foundation, and it is far to be completed. This Strategy is designed to place the Bank at the centre of Africa's transformation and to improve the quality of Africa's growth. It aims to broaden and deepen that process of transformation, mainly by ensuring that growth is shared and not isolated, for all African citizens and countries. It also aims to bring about growth that is not just **environmentally sustainable**, but also **economically empowering**. When growth is inclusive as well as *green*, it creates the jobs that the continent needs now and that it will need in ever greater numbers as millions more young people enter the job market, with energies and aspirations to match.

The Strategy is built around two objectives, supported by five operational priorities in which the Bank has unmatched advantage, expertise, access and trust.

The ten-year Strategy is focused on two objectives to improve the quality of Africa's growth: inclusive growth, and the transition to green growth.

Inclusive growth. The first and overarching objective is to achieve growth that is more inclusive, leading not just to equality of treatment and opportunity but to deep reductions in poverty and a correspondingly large increase in jobs. The Bank will invest in infrastructure that unlocks the potential of the private sector, championing gender equality and community participation. It will help improve skills for competitiveness, ensuring that those skills better match the opportunities and requirements of local job markets.

Green growth. The second objective is to ensure that inclusive growth is sustainable, by helping Africa gradually transition to *green growth* that will protect livelihoods, improve water, energy and food security, promote the sustainable use of natural resources and spur innovation, job creation and economic development. Priorities in reaching green growth include building resilience to climate shocks, providing sustainable infrastructure, creating ecosystem services and making efficient and sustainable use of natural resources (particularly water, which is central to growth but most affected by climate change).

The Strategy outlines **five operational priorities** for the Bank to deliver its work and improve the quality of growth in Africa. These are areas in which the Bank has the greatest comparative advantage and proven track record. Over at least a decade, the Bank has repeatedly confirmed that they provide a compelling and consistent framework for the Bank's operations.

Infrastructure development. Africa still has massive infrastructure needs. It invests only 4% of its GDP in infrastructure, compared with 14% in China. Bridging the infrastructure gap could increase GDP growth by an estimated 2% a year. The Bank has made significant contributions to infrastructure development in Africa, and tens of millions of Africans are now better off thanks to Bank investments in transport, energy and water. The Bank intends to scale up infrastructure financing to the continent significantly, not just through its own lending but by leveraging its financial resources.

Regional economic integration. Integration is essential for Africa to realize its full growth potential, to participate in the global economy and to share the benefits of an increasingly connected global marketplace. Having 54 individual countries, often without the physical and economic machinery to act in tandem, seriously limits this possibility. The Bank is well positioned to play a leading role in fostering Africa's economic integration to create larger, more attractive markets, to link landlocked countries, including fragile states, to international markets and to support intra-African trade.

Private sector development. The dynamics of wealth and job creation in Africa, and a number of the tasks of government, are increasingly driven by private rather than public funds. Working both directly and indirectly with governments, the Bank continues to be an increasingly active partner and facilitator for private investment in Africa. Delivering finance and providing advice and technical assistance, it will design activities that respond to the specific needs, opportunities and challenges of the private sector. In strengthening the financial sector, it will stimulate lending to micro, small and medium-size enterprises, help develop local capital markets, promote better governance and risk management of financial institutions and promote the adoption and implementation of financial standards and regulations.

Governance and accountability. Economic growth can only be built on the firmest foundations of just, transparent and efficient governance and institutions administered by the capable state. Responding to demands in Africa for better governance and basic services, the Bank will assist institutions that support inclusion and promote accountability, for example by strengthening the capacities of parliamentarians, the media and civil society organizations. To improve public financial management, the Bank will do more to support fiscal decentralization and domestic resource mobilization.

Skills and technology. Unemployment across Africa is unacceptably high, especially among young people. To increase the supply of skilled workers, the Bank will step up its support for technical and vocational training linked to specific needs in the labour market. The aim is to equip young people with the right skills for both the formal and informal sectors, including the skills to create small businesses.

Within this framework, AfDB is financing in the contest of its Energy and Power sector geothermal exploration and development projects in East Africa countries, such those briefly summarized below.

Menengai geothermal development project (approved in 2011). As access to electricity in Kenya was relatively limited at the time, diversification of sources of electricity became a real priority issue for the country. Aware of its huge geothermal potential, Kenya has committed in its 2030 vision to increasing its electricity production capacity through the Menengai geothermal development project funded with US $502.9 million from the Bank. With an estimated capacity of 400 MW, Menengai shall provide reliable, clean and affordable electricity to thousands of households and industries.

The project objectives were:

- To increase geothermal energy production capacity in Kenya by 400 MW.
- To provide a reliable, clean and affordable electricity supply to 500,000 households and 300,000 micro-enterprises.
- To accelerate the energy transition of the Kenyan economy through increasing the proportion of geothermal in the national energy mix.
- To reduce the frequency of power outages caused by the volatility of hydroelectric production.

Geothermal Exploration Project, Djibouti (2013). The Republic of Djibouti has for many years been engaged in geothermal exploration in the Lac Asal region. It received funding in 2013 from various donors including the World Bank, the African Development Bank (AfDB), the French Development Agency (AfD), the OPEC Fund for International Development, the Global Environment Facility (FEM) and the Energy Sector Management Assistance Program (ESMAP) to finance geothermal resource exploration in the Fialé Caldera (Asal Rift area) and assess the feasibility of commercial geothermal power generation.

The project is carried out in three phases: **(i)** the first phase consists of the exploration of the geothermal field of Lake Asal and the confirmation of the characteristics of this geothermal resource (about 62 M USD); **(ii)** the second phase includes the development of the geothermal field and the construction of a geothermal power plant with an installed capacity of 20 MW; and **(iii)** the third phase will consist of expanding the capacity of the geothermal power plant to 50 MW.

Geothermal Energy Development Project, Tanzania (2017). The Climate Investment Funds (CIF) has approved 21.7 M USD for the United Republic of Tanzania to finance its Geothermal Energy Development Project at Ngozi geothermal prospect in southwestern Tanzania. Funded under the CIF's Scaling-up Renewable Energy Program (SREP), the project received 5 M USDn as loan and 16.73 M USD in grant resources to be implemented by AfDB. The project included the drilling of three exploratory slim holes and the performance of well testing operations at Ngozi geothermal site. This SREP highly concessional finance was instrumental in mitigating the high-risk nature of geothermal prospection and field development.

2.8 World Bank (WB)

With 189 member countries, staff from more than 170 countries, and offices in over 130 locations, the World Bank Group (https://www.worldbank.org/en/) is a unique global partnership: five institutions working for sustainable solutions that reduce poverty and build shared prosperity in developing countries. The WB mission is focused on two global objectives:

- To end extreme poverty, by reducing the share of the global population that lives in extreme poverty to 3% by 2030.
- To promote shared prosperity, by increasing the incomes of the poorest 40% of people in every country.

The WB Group is one of the world's largest sources of funding and knowledge for developing countries. Its five institutions share a commitment to reducing poverty, increasing shared prosperity, and promoting sustainable development:

- IBRD: The International Bank for Reconstruction and Development. It provides financial development and policy financing.
- IDA: The International Development Association, provides zero-to low-interest loans and grants.
- IFC: The International Finance Corporation, mobilizes private sector investment and provides advice.
- MIGA: The Multilateral Investment Guarantee Agency, provides political risk insurance (guarantees).
- ICSID: The International Centre for Settlement of Investment Disputes.

Partnering with Governments. Together, IBRD and IDA form the World Bank, which provides financing, policy advice, and technical assistance to governments of developing countries. IDA focuses on the world's poorest countries, while IBRD assists middle-income and creditworthy poorer countries.

Partnering with The Private Sector. IFC, MIGA and ICSID focus on strengthening the private sector in developing countries. Through these institutions, the WB Group provides financing, technical assistance, political risk insurance, and settlement of disputes to private enterprises, including financial institutions.

In addition to the co-financing of the Djibouti Geothermal Project with AfDB, WB recently financed two projects in Ethiopia and Kenya.

- Geothermal Sector Development Project, aimed at developing geothermal resources in Ethiopia, consists in an IDA Grant of 24.5 M USD and an IDA credit of 178.5 M USD. There are four components to the project, the first component being **Aluto** geothermal site development. This component will finance goods, including drilling consumables and associated materials; services, including drilling contractors, the supervision engineer, reservoir engineering, and management; drilling and testing of up to 22 wells; and design and construction of a steam-gathering system connecting the producing and injection wells. Drilling at Aluto as well as the supply of drilling rigs (3rd component) has been awarded to a consortium between KERUI and KenGen. Drilling rig supply is ongoing, while drilling is expected to begin in late 2020.

The second component is the **Alalobad** geothermal site development. This component will finance goods, including drilling consumables and associated materials; services, including drilling contractors and the supervision engineer; and drilling and testing of about four wells. Funds will be used for drilling and testing activities, in order to establish the economic viability of the geothermal resources and finalize a feasibility study of the Alalobad geothermal site.

The third component is the drilling rigs, associated accessories and spare parts. This component will finance goods, in particular two full-size modern diesel electric drilling rigs with all ancillary drilling equipment, the equipment for well cementing and aerated drilling, and a complete inventory of spare parts.

Finally, the fourth component is the legal, institutional, and regulatory framework development. WB consultants have supported the GoE to prepare the Geothermal

Proclamation 981/2016 and the Geothermal Regulations No. 453/2019. The Ethiopian Energy Authority (EEA) is presently promulgating all the directives regulating the geothermal licensing process, the authorization of exploration and development programs, the design and execution of well drillings.

- Olkaria Geothermal Field, Kenya. The World Bank program of support for the medium term, FY2014 to FY2018, addresses Kenya's development challenges through three areas of engagement: (i) competitiveness and sustainability, (ii) protecting the vulnerable and helping them develop their potential, and (iii) building consistency and equity. Through IDA support 280 MW new capacity has been commissioned in Olkaria geothermal field managed by KenGen, almost doubling Kenya's developed geothermal capacity to 579 MW from 241 MW in 2013.

WB is channelling funds and efforts on geothermal resources development through the **ESMAP** (Energy Sector Management Assistance Program). ESMAP (https://www.esmap.org/) is a partnership between the WB Group and 18 partners to help low and middle-income countries reduce poverty and boost growth, through environmentally sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the WB Group's country financing and policy dialogue in the energy sector. Through the WB Group, ESMAP works to accelerate the energy transition required to ensure access to affordable, reliable, sustainable and modern energy for all. It helps to shape WB Group strategies and programs to achieve WB Group Climate Change Action Plan targets: 28% of WB Group financing with climate co-benefits; scale up 20 GW in renewable energy generation and integrate an additional 10 GW of variable renewable energy sources into grids over 5 years; mobilize 25 billion USD in commercial funds for clean energy; invest at least 1 billion USD to promote energy efficiency and resilient buildings by 2020; and, increase support to policy actions for sector reform, including for fossil fuel subsidies.

Global Geothermal Development Plan (GGDP) (https://esmap.org/GGDP). The GGDP is an ambitious initiative by the WB's ESMAP and other multilateral and bilateral development partners to transform the energy sector of developing countries by scaling up the use of geothermal power. GGDP is breaking down barriers to geothermal energy expansion by mobilizing financing to share the risks of investments in early-stage drilling. Donors have responded positively to the GGDP. As of March 2015, 235 M USD have been raised, to be deployed through a new window within the Clean Technology Fund (CTF) for funding geothermal exploratory investments as part of the Utility Scale Renewable Energy Program.

To lead the design and implementation of the GGDP, ESMAP has raised and set aside 7.5 M USD over 2013-16 to: (i) identify and develop a pipeline of investments in geothermal energy resource validation through drilling; (ii) promote knowledge dissemination and capacity building; and (iii) advocate for additional concessional capital mobilization. Currently, ESMAP is supporting identification, preparation, and supervision of 8 geothermal investment operations (including Djibouti). In addition, 11 countries have benefited from technical assistance deployed by ESMAP (including Djibouti, Kenya and Tanzania).

Other GDDP initiatives include the performance of studies on specific topics, with the publication of relevant reports:

- Definition of global standards for Geothermal resources Classification;
- Comparative Analysis of Approaches to Geothermal Resource Risk Mitigation (ESMAP, 2016a);
- Geothermal Handbook: planning and financing power generation (ESMAP, 2012);
- Greenhouse Gases from Geothermal power production (ESMAP, 2016b).

On the other hand, **IFC** sponsored a study about the "Success of geothermal wells: a global study" (IFC, 2013) which is a useful source of data about the success rate of geothermal exploration and development wells drilled in different countries, geodynamic environments and temperature conditions.

2.9 New Zealand Ministry of Foreign Affairs & Trade (NZ MFAT)

New Zealand is one of the Countries in which the utilization of geothermal energy for power production started. New Zealand was in particular the pioneer in the utilization of water dominated geothermal reservoirs after the 2nd World War, while Italy was the pioneer of the utilization of steam dominated reservoir starting before the 2nd World War.

Through the Ministry of Foreign Affairs & Trade (MFAT, https://www.mfat.govt.nz/en/aid-and-development/), NZ is financing and operating an aid program towards countries located in the Pacific region, Asia, Africa and Latin America and the Caribbean, in addition to Multilateral initiatives (Hassall, 2017). Investment in renewable energy is among the MFAT priorities to "Expand access to affordable, reliable and clean energy". MFAT aid program focus is on utilizing NZ's geothermal experience and expertise in R&D, drilling, manufacturing, supplies, construction and development.

As a self-defined small donor, New Zealand recognises four factors that assist geothermal development:

1. Well characterised geothermal resource;
2. Adequate human and engineering resources;
3. An investment enabling regulatory process;
4. Access to finance (equity, debt) and opportunity to leverage.

As far as MFAT geothermal initiatives for East Africa, they are coordinated by the **NZ Africa Geothermal Facility (AGF)** with a budget of 10 M NZD over 5 years. AGF has been established under the MFAT and Africa Union Commission partnership arrangement, with a Project Manager based in Addis Ababa, Ethiopia. AGF provides geothermal technical assistance and capacity building to 11 countries in East Africa.

An ongoing initiative is a partnership with the Government of Comoros and UNDP for surface exploration and test drilling activities in the Comoros Islands. The drilling project has obtained funds from the GRMF through a successful application coordinated by NZ AGF.

2.9.1 Geothermal Institute of Auckland University (New Zealand)

As one of the premier geothermal research and training centres in the world, the Geothermal Institute has been providing research and development, testing and laboratory services, commercial and consultancy services, as well as education and training for the New Zealand and international geothermal industries, since 1978.

The Geothermal Institute offers students a range of qualifications to build their knowledge from Postgraduate Certificate level, all the way to doctoral study. These programmes involve important partnerships between other NZ organisations in the geothermal sector that provide guest lecturers and facilitate field trips for both Postgraduate Certificate and Master of Energy students. To help geothermal professionals up skill while working, the Institute delivers industry training both in NZ and around the world.

The Institute at the Auckland University has been a reference academic destination about geothermal energy for many students coming from East African countries.

2.10 International Geothermal Association (IGA)

IGA (https://www.geothermal-energy.org/) is a global geothermal organization aiming at being the leading world authority in matters concerning the research and development of geothermal energy by setting educational standards and offering worldwide energy solutions and in-house technical support, in particular for countries in early stages of geothermal development.

IGA connects the global geothermal community, serving as a platform for networking opportunities aimed at promoting and supporting global geothermal development. IGA embodies a wide variety of members ranging from academy to industry representatives with about 5,000 members worldwide and 31 affiliated organizations.

The IGA aims at being the leading world authority in matters concerning the research and development of geothermal energy by setting educational standards and offering worldwide energy solutions and in-house technical support, with special support for countries in early stages of geothermal development.

IGA is committed to make geothermal energy a significant part of future renewable energy mix. Thus, it encourages, facilitates and promotes the development of geothermal resources, as well as innovative research in geothermal technologies, through visible and integrated position and representation of geothermal power, heat, geo-exchange, cooling and other uses of geothermal resources.

IGA provides geothermal education in terms of the best practices and unbiased benefits of developing the utilization of Earth's energy for direct use, heat and power generation. IGA offers financial support to educational geothermal events especially in countries with emerging geothermal markets. It increases the visibility of geothermal industry encouraging, facilitating and promoting the coordination of activities related to worldwide research and application of geothermal resources, including conferences, workshops, congresses.

IGA organizes the **World Geothermal Congress** which has become the major international event for the geothermal industry stakeholders. Next Congress was planned in Reykjavik from April 27 to May 1, 2020, but has been rescheduled always in Reykjavik on May 21-26, 2021, due to the COVID-19 pandemic disease (https://www.wgc2020.com/). Besides the opportunity to display the new achievements in R&D and field activities, the WGC gives the opportunity to representatives of the Countries with active geothermal operations to present the Country's status on geothermal energy.

IGA is operating the **IGA Academy**, a world class teaching and training centre that offers training courses, webinars, e-learning as well as corporate in-house courses. After the successful course completion, all participants receive the IGA Academy Certificate. Courses are conducted by IGA-approved professionals and evaluated by the IGA Board. They include: on-site training courses, in-house courses, on-line courses (webinars), free IGA webinars.

Through its web site, IGA is providing the search over an extended **Geothermal Paper Database** which presently allows to search over 18,000 technical papers. It also offers the access to its **Geothermal Power Database** with data related to installed thermal and electric power as well as thermal and electric energy generation for any Country with on-going geothermal activities. The web site has also a geothermal news section and allows the view and download of the **IGA News** (https://www.geothermal-energy.org/iganews/), a quarterly newsletter with news and papers dealing with geothermal energy worldwide.

IGA is also involved in projects dealing with the promotion of geothermal industry in specific regions as well as with the setting of industrial standards and approaches. It is worth to remind the project performed by IGA in collaboration with UNECE (https://www.unece.org/energywelcome/areas-of-work/unfc-and-sustainable-resource-management/applications/energyseunfc-re/unfc-and-geothermal-energy.html) to develop Specifications and Guidelines for the application of UNFC-2009 to geothermal energy and to maintain them evergreen in a manner consistent with their proper application through regular and periodic review.

Growing awareness and interest in renewable energy resources, including geothermal resources, has highlighted a need to normalize the way in which renewable energy potential is reported. The renewable energy industry has become a fully commercialized sector, in which several oil and gas majors have already started to play a significant role.

These players have voiced a need for a common platform to assess and compare in a transparent way the potential of their renewable and non-renewable energy portfolios. The IGA-UNECE project developed the Specifications for Application of UNFC-2009 to Geothermal Energy Resources, which became operational on Sept. 30, 2016.

2.11 Geothermal Resources Council (GRC)

The GRC (https://geothermal.org/about.html) is a tax-exempt, non-profit, educational association formed in 1972. The GRC actively seeks to expand its role as a primary professional educational association for the international geothermal community. The GRC serves as a focal point for continuing professional development for its members through its outreach, information transfer and education services.

GRC is affiliated to IGA and the Geothermal Energy Association (GEA). At the end of 2019 the membership of the GRC amounted to 1,220 from 43 different countries, but with a special focus on USA and the Americas.

The elements of GRC's Strategic Plan, updated in 2019, are:

Vision - What GRC wants for the world.

An open exchange of information to raise the recognition and acceptance of geothermal energy across society to meet the world's energy demand in a manner that is environmentally responsible.

Mission - How GRC will achieve its vision.

Be a prestigious, dynamic, and diverse professional association that advances the global geothermal industry and educates through transfer of robust research, knowledge and guidance.

Goals - GRC general long-term aspirations for the organization.

- Increase the importance of geothermal resources in helping meet global energy demands.
- Serve as a source and venue for geothermal knowledge exchange.
- Build a strong membership.
- Be fiscally responsible.
- Produce professional quality products and services.

Core Values - Principles for decision-making.

- Financially fit and sustainable.
- Member focused.
- High professional and technical quality.
- Faithful to Scientific Principals.
- Serve as a Public Forum.
- Collaborative and Cooperative.

Objectives - How GRC will achieve its goals in the given time frame.

- Enhance Community Networking and Education– bring people together in GRC community, provide materials and venues for education and debate, and define its key global messages that enable growth of the geothermal industry;
- Enhance Public Awareness and Education– improve public relations for the geothermal energy community by developing and executing a marketing and communications plan;

- Introduce Policy and Regulatory Improvements– work with governments and regulatory agencies to incentivize demand and adoption of geothermal energy;
- Balance the Budget – to operate with a budget surplus by providing self-supporting activities;
- Ensure Internal Processes– improve professional quality and enhance coordination and communication within the GRC.

Among its Education Program, GRC convenes special meetings, workshops, and conferences on a broad range of topics pertaining to geothermal exploration, development and utilization. On a contract basis, the GRC provides comprehensive professional meeting services to fulfil industry and agency needs. The most important event is the **GRC Annual Meeting**, which was planned in Durban, South Africa during 26-28 May 2020, but which has been postponed until next year because of COVID-19 pandemic disease (https://www.globalresearchcouncil.org/news/2020-annual-meeting/). Technical papers presented at the Annual Meeting are published on the **GRC Transactions**.

The GRC publishes the online **GRC Bulletin** (6 issues per year), which features articles on technical topics and geothermal development issues, as well as commentaries and news briefs. In addition, the GRC publishes an online **Registry of Geothermal Services & Equipment**, a unique web site that provides business, consulting and research contacts throughout the international geothermal community. With financial assistance from private and/or government institutions, the GRC has published a number of Special Reports about various aspects of geothermal resources and development.

The GRC maintains a comprehensive geothermal technical library at its offices in Davis, California, and on its library website at www.geothermal-library.org . The online **GRC Geothermal Library** contains over 40,000 records on all aspects of geothermal energy, including exploration, reservoir engineering, power plant design and operation, direct use, geothermal heat pumps, regulatory issues, energy policy, energy markets, news briefs, and more. The database provides article-level citations to: all GRC Transactions (1977 to present), all GRC Special Reports, numerous feature articles and news briefs from the GRC Bulletin (1973 to present), corporate and academic technical reports, journals, and books. All users can access over 19,000 articles for free as downloadable PDF files from a number of publications, including most of the GRC Transactions, Special Reports and Bulletins.

The GRC also maintains a blog of **Global Geothermal News** at www.geothermalresourcescouncil.blogspot.com. Global Geothermal News can be received by email with a free subscription.

2.12 International Renewable Energy Agency (IRENA)

IRENA (www.irena.org) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

With a mandate from countries around the world, IRENA encourages governments to adopt enabling policies for renewable energy investments, provides practical tools and policy advice to accelerate renewable energy deployment, and facilitates knowledge sharing and technology transfer to provide clean, sustainable energy for the world's growing population.

In line with these aims, IRENA provides a wide range of products and services, including:

- Annual reviews of renewable energy employment;

- Renewable energy capacity statistics;
- Renewable energy cost studies;
- Renewables Readiness Assessments, conducted in partnership with governments and regional organisations, to help boost renewable energy development on a country by country basis;
- The Global Atlas, which maps resource potential by source and by location;
- Renewable energy benefits studies;
- REmap, a roadmap to double renewable energy use worldwide by 2030;
- Renewable energy technology briefs;
- Facilitation of regional renewable energy planning;
- Renewable energy project development tools like the Project Navigator, the Sustainable Energy Marketplace and the IRENA/ADFD Project Facility.

With more than 180 countries actively engaged, IRENA promotes renewable resources and technologies as the key to a sustainable future and helps countries achieve their renewable energy potential.

Data & Statistics

Detailed, accurate and timely data and statistics are essential for the monitoring and evaluation of renewable energy policies and deployment. IRENA helps analysts, policy makers and the public make informed decisions by providing access to comprehensive and up-to-date renewable energy data.

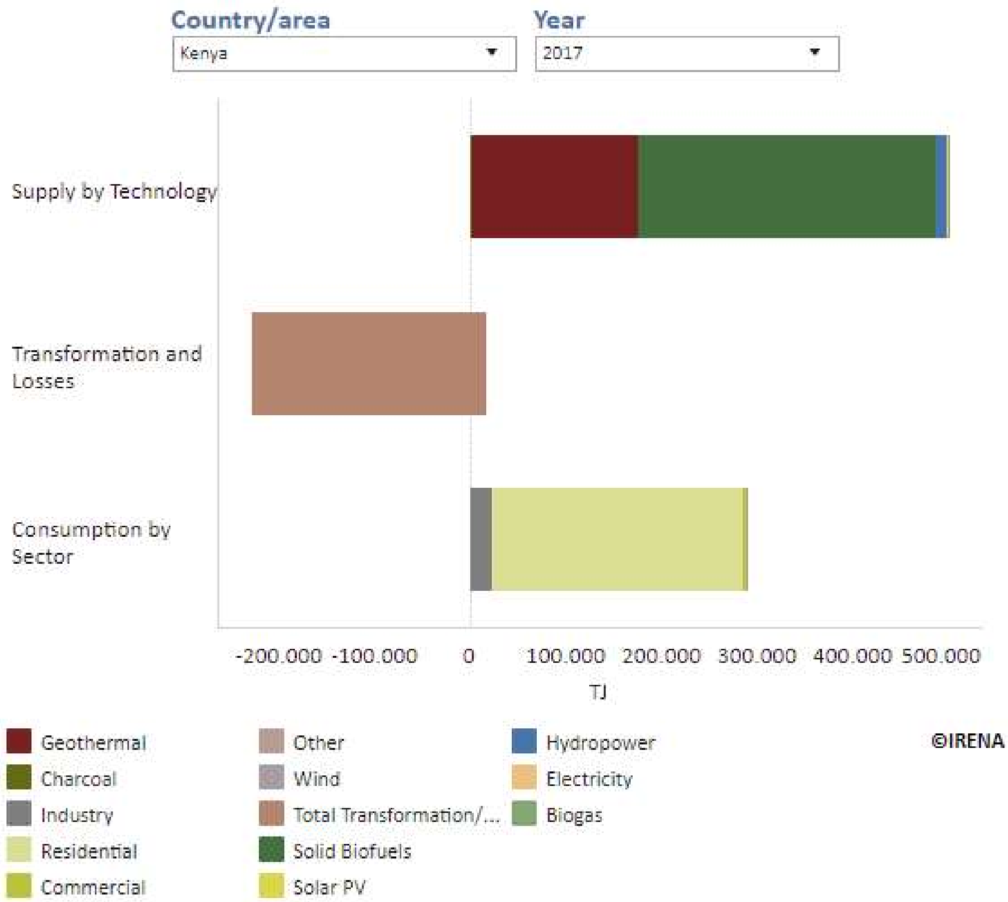
IRENA publishes detailed statistics on renewable energy capacity, power generation and renewable energy balances. This data is collected directly from members using the IRENA Renewable Energy Statistics questionnaire and is also supplemented by desk research where official statistics are not available. Renewable power-generation capacity statistics are released annually in March. Additionally, renewable power generation and renewable energy balances data sets are released in July.

IRENA’s statistics unit helps members to strengthen their data collection and reporting activities through training and methodological guidance. Member countries are encouraged to participate in this process.

An example of the data readily available on the IRENA web site are those related to the energy balance for each country.

Figure 32 shows the energy balance for year 2017 of Kenya. Geothermal energy supplied 175,343 TJ, solid biofuels 310,381 TJ and Hydro 11,788 TJ. The fraction of energy supply by geothermal is a unique feature of Kenya over the other African countries, while the huge supply of energy from solid biofuels is a constant for most of sub-Saharan countries.

Figure 32. Renewable energy balance in Kenya, 2017 (Source: https://www.irena.org/Statistics/View-Data-by-Topic/Renewable-Energy-Balances/Country-Profiles)



Statistics on renewables, country and regional assessment and featured studies are periodically published by IRENA. Examples are the "Geothermal power: Technology brief" (IRENA, 2017) and the "Renewable Energy Country Profiles: Africa" (IRENA, 2011).

IRENA is also the promoting agency for the Global Geothermal Alliance (GGA).

2.12.1 Global Geothermal Alliance (GGA)

Launched at COP21 (the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC), held in Paris on December 2015) the **Global Geothermal Alliance (GGA)** (http://www.globalgeothermalalliance.org/) serves as a platform for dialogue, cooperation and coordinated action between the geothermal industry, policy makers and stakeholders worldwide.

As stated in the Joint Communiqué on the Global Geothermal Alliance, the GGA is a coalition for action to increase the use of geothermal energy, both in power generation and direct use of heat. It calls on governments, business and other stakeholders to support the deployment of realizable geothermal potential. The Alliance has an aspirational (quite ambitious) goal to achieve a five-fold growth in the installed capacity for geothermal power generation and more than two-fold growth in geothermal heating by 2030.

GGA has 46 Member Countries including geothermal resource-rich countries with established or emerging geothermal markets, along with other countries that wish to support the activities of the Alliance, and 39 Partners. Partner institutions include:

- Development partners, international and bilateral development organisations, international financial institutions, institutional investors, international organisations, and other development partners involved with geothermal energy.
- Geothermal industry represented by geothermal business associations at the global, regional and national levels.
- R&D and academic organisations operating in the geothermal energy field at regional, national or sub-national levels.

The GGA Action Plan was endorsed by Members and Partners in May 2016, based on the principles stipulated in the GGA Joint Communique. It is set to coordinate closely with existing structures, programmes and facilities that share the common objective of promoting geothermal energy deployment at the international, regional and national levels. The Alliance operates based on activities linked to the priority action areas identified in the GGA Action Plan, and is supported in implementation as well as funding by committed Members and Partners. Action Plan components are as follows:

ACTION PLAN 1

- Resource and Market Assessment;
- Mapping of geothermal resources as well as identification of existing and potential geothermal markets and near terms projects in the pipeline.

ACTION PLAN 2

- Needs and Obstacles Assessment;
- Scoping of the needs for assistance in removing obstacles of policy, regulatory, funding or capacity building nature.

ACTION PLAN 3

- Enabling Frameworks;
- Supporting the development of effective enabling frameworks and associated mechanisms to achieve national objectives for geothermal energy deployment.

ACTION PLAN 4

- Global Geothermal Network;
- Establishing and improving a robust global network of geothermal energy experts building upon existing networks; promoting geothermal energy's role in supporting decarbonisation strategies and the implementation of climate plans.

The GGA organizes events such as the "High-Level Conference of the Global Geothermal Alliance: Working Together to Promote Geothermal Energy Towards a Sustainable Energy Future", held in Florence on Sept. 11-12, 2017; periodic GGC Meetings such that held at the IRENA 10^{th} Assembly held in Abu Dhabi on Jan. 11-12, 2020; and technical workshops, such as the "Workshop on UNFC Geothermal Specifications in Ethiopia", held in Addis Ababa on Feb. 05 – 07, 2019.

2.13 International Energy Agency (IEA)

Created in 1974 to ensure the security of oil supplies, the International Energy Agency (https://www.iea.org/) has evolved over the years. While energy security remains a core mission, the IEA today is at the centre of the global energy debate, focusing on a wide variety of issues, ranging from electricity security to investments, climate change and air pollution, energy access and efficiency.

The IEA is at the heart of global dialogue on energy, providing authoritative analysis, data, policy recommendations, and real-world solutions to help countries provide secure and sustainable energy for all. The IEA was created in 1974 to help co-ordinate a collective response to major disruptions in the supply of oil. While oil security remains a key aspect of IEA work, the IEA has evolved and expanded significantly since its foundation. Taking an all-fuels, all-technology approach, the IEA advocates policies that enhance the reliability, affordability and sustainability of energy. It examines the full spectrum issues including renewables, oil, gas and coal supply and demand, energy efficiency, clean energy technologies, electricity systems and markets, access to energy, and demand-side management.

Since 2015, the IEA has opened its doors to major emerging countries to expand its global impact, and deepen cooperation in energy security, data and statistics, energy policy analysis, energy efficiency, and the growing use of clean energy technologies.

The IEA is an autonomous inter-governmental organisation within the OECD framework, headed by its Executive Director. The IEA is made up of 30 member countries. In addition, thanks to its successful open-door policy to emerging countries, the IEA family also includes eight association countries, with two other countries seeking accession to full membership.

IEA analysis is built upon a foundation of activities and focus areas including data and statistics, training, innovation and international cooperation, as listed below:

Promoting energy efficiency - IEA help governments improve standards, advising them on developing, implementing, and measuring the impact of efficiency policies.

Ensuring energy security - IEA work on energy security ensures that markets remained well supplied, providing information to governments, and helping improve system resilience.

International collaborations - IEA works with a broad range of international organisations and forums to ensure secure, affordable and sustainable energy systems.

Training - For more than four decades, IEA has carried out training activities around the world on energy statistics, modelling, technology, energy efficiency and renewable policies.

Technology collaboration - With about 40 research collaborations and about 6,000 experts, IEA technology programme provides the basis for international public and private research partnerships.

Global engagement - Since 2015, IEA has opened its doors to eight major emerging economies for a new era of international energy co-operation.

Industry engagement - Meeting with various industry groups on a regular basis, IEA gains precious insights on how policies shape real-world investments and actions.

Data and statistics - Data collection has been at the heart of the IEA's work since its creation, with official energy statistics from more than 100 countries collected on a monthly or annual basis.

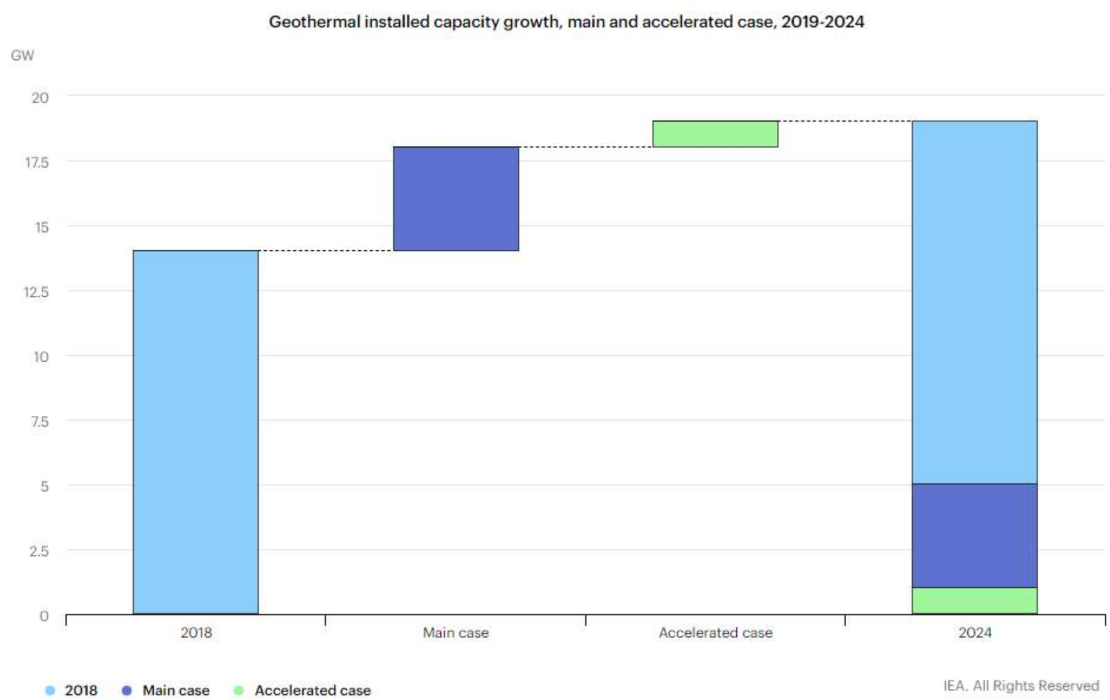
Consistent, accurate and timely energy data and statistics are fundamental to developing effective and efficient national energy policies, as well as a key element in longer-term planning for investment in the energy sector. To this end, the **IEA Energy Data Centre** provides the world's most authoritative and comprehensive source of global energy data. The IEA collects, assesses and disseminates energy statistics on supply and demand, compiled into energy balances. In addition, the Energy Data Centre has developed a number of other key energy-related indicators, including energy prices, public RD&D and measures of energy efficiency, with other measures in development.

The time series stretches back to 1971, and currently covers up to 95% of global energy supply and over 150 countries. The focus is on quality, comparability, and alignment with internationally agreed definitions and methodologies, and close collaboration with national offices responsible for energy statistics and other relevant stakeholders. This emphasis on sound data provides a unique platform for modelling work and tracking both short-term shifts and long-term trends in countries' energy transitions, particularly for clean energy. Furthermore, the IEA Energy Data Centre has established close cooperation with national and regional organisations on training and capacity building activities. As well as allowing for expanded coverage, this further ensures the quality of the Centre's data products.

IEA publish on a regular basis comprehensive reports on World Energy Outlook as well reports focused on different energy sectors and world regions and countries. Examples are the Country Report "Africa Energy Outlook 2019" and the Fuel Report "Renewables 2019" (IEA, 2019a; 2019b).

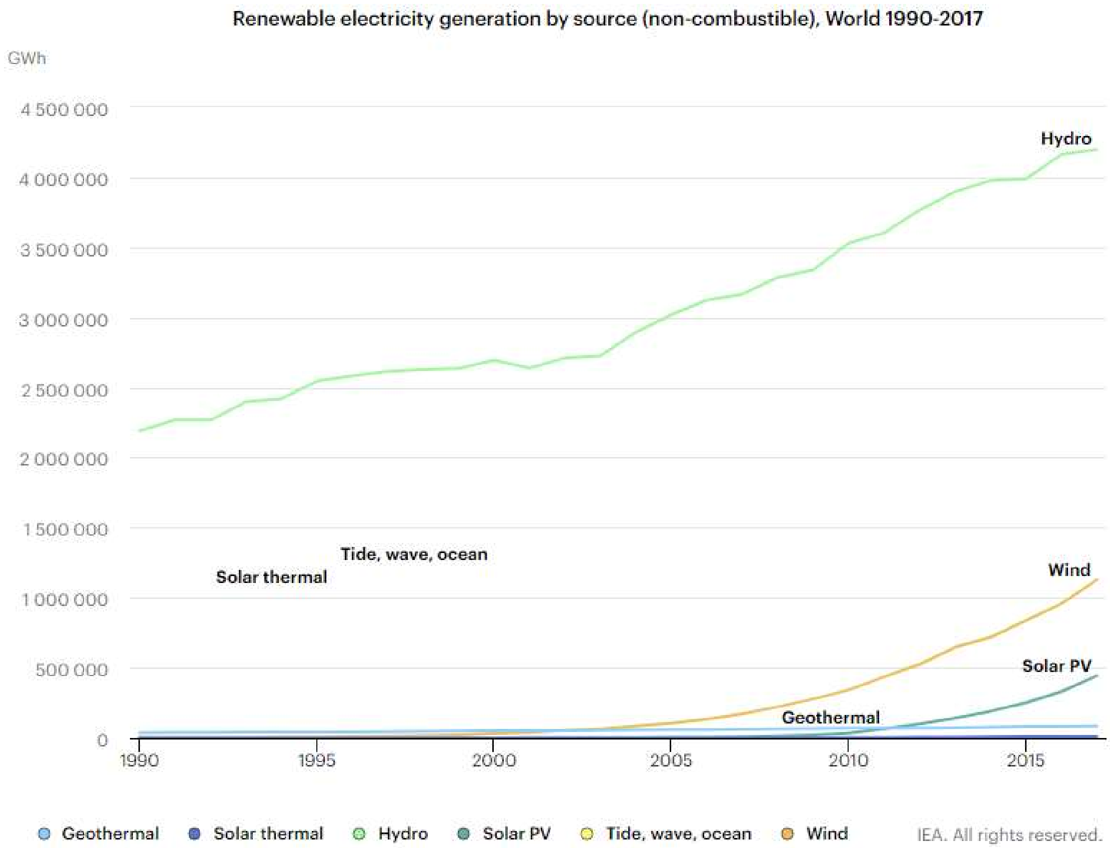
The latter examines also the scenarios of geothermal installed capacity growth from 2018 to 2024 for both a main and an accelerated case, as shown in **Figure 33**. From about 14 GW in 2018, installed power is expected to increase by 4 GW for the main case with an additional 1 GW for the accelerated case.

Figure 33. Geothermal installed capacity growth: main and accelerated cases from 2019 to 2024 (Source: https://www.iea.org/data-and-statistics/charts/geothermal-installed-capacity-growth-main-and-accelerated-case-2019-2024)



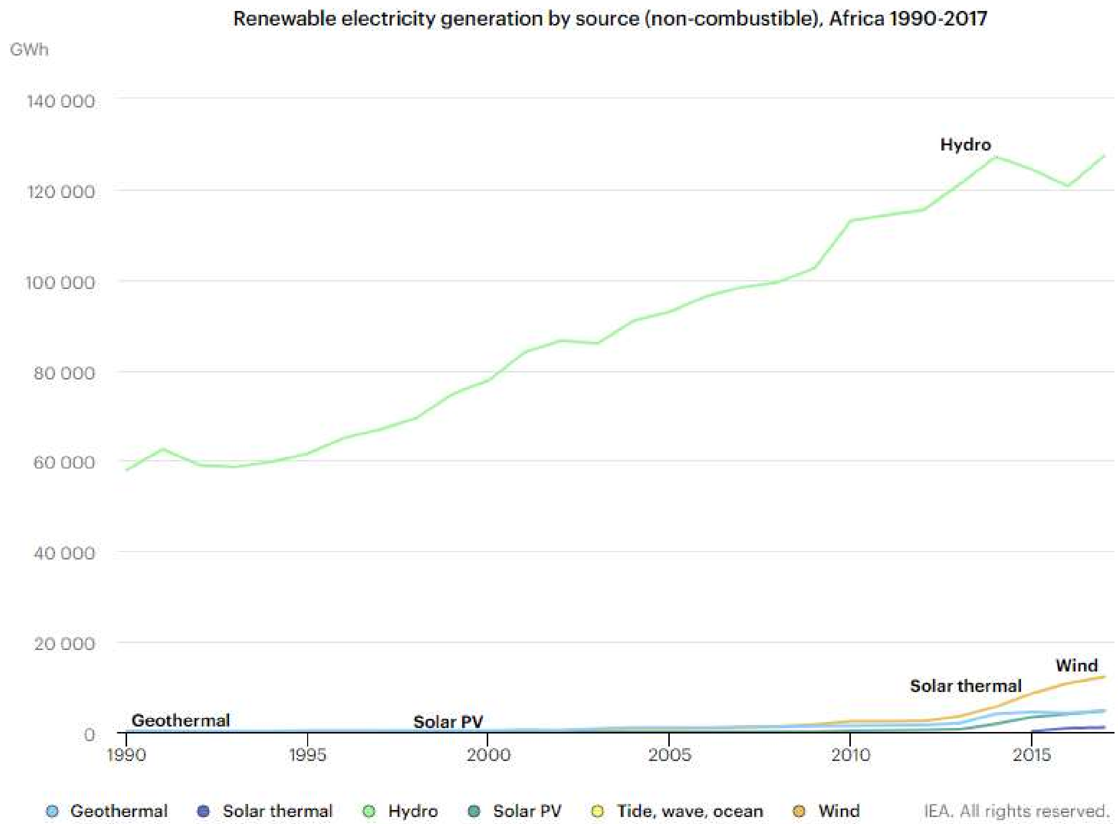
The Data and statistics web page (https://www.iea.org/data-and-statistics) allows to access energy data at world, region, or country levels, as well as for different energy sources. **Figure 34** shows the annual electricity generation by different renewable sources in the World since 1990 to 2017, which is still dominated by Hydro (4.2E6 GWh) with important contribution from Wind (1.1E6 GWh) and Solar PV (0.4E6 GWh). While predominant over the other renewables (but Hydro) until 2002, Geothermal was characterized by a steady increment from 36,426 GWh in 1990 to 85,348 GWh in 2017, without the accelerated generation scenarios experienced by Wind and Solar PV since approx. 2003 and 209, respectively.

Figure 34. World renewable electricity generation by source (non-combustible) from 1990 to 2017 (Source: https://www.iea.org/data-and-statistics)



The same data related to African countries is shown in **Figure 35**. With respect to the World data, Hydro (127,417 GWh) is by far the dominating renewable energy source for the generation of electric energy, followed by Wind (12,280 GWh). Surprisingly, Geothermal (4,819 GWh) is still ahead of Solar PV (4,670 GWh) despite the enormous solar resources at tropical latitudes in North and South Africa countries. To be noted that at present Geothermal electric energy is still entirely generated in Kenya. It can be expected that in coming years the electric generation from renewable sources will follow in Africa what has been observed in the World, with a remarkable increment of Wind and Solar PV.

Figure 35. Africa renewable electricity generation by source (non-combustible) from 1990 to 2017 (Source: https://www.iea.org/data-and-statistics)



2.14 Japan International Cooperation Agency (JICA)

Established as an Incorporated Administrative Agency, JICA (https://www.jica.go.jp/english/index.html) aims to contribute to the promotion of international cooperation as well as the sound development of Japanese and global economy by supporting the socioeconomic development, recovery or economic stability of developing regions. JICA assists and supports developing countries as the executing agency of Japanese ODA (Official Development Assistance, https://www.mofa.go.jp/policy/oda/).

In accordance with its vision of "Leading the world with trust", JICA supports the resolution of issues of developing countries by using the most suitable tools of various assistance methods and a combined regional-, country- and issue-oriented approach. Since joining the Colombo Plan in 1954, Japan has been providing financial and technical assistance to developing countries through ODA, aiming to contribute more proactively to the peace, stability and prosperity of the international community.

JICA is in charge of administering all ODA such as Technical Cooperation, Finance and Investment Cooperation and Grants in an integrated manner, except for contributions to international organizations. JICA, the world's largest bilateral aid agency, works in over 150 countries and regions and has some 90 overseas offices.

Among the sectors of JICA intervention, the support to geothermal development in Latin America, Asia and East Africa is one of the most remarkable. As one of the country leaders in geothermal resources utilization, Japan can offer technical and scientific support along the entire chain from exploration to exploitation of geothermal resources. In addition, Japan is a leader in the supply of condensing geothermal turbines through 3 major manufacturers, namely Toshiba Power System, Mitsubishi Heavy Industries and Fuji Electric Co. Mitsubishi also entered into the market of ORC turbines supply through the purchase of the Italian company Turboden, a leader in the ORC market, where the Israeli-USA company ORMAT is the major World player. JICA is promoting through both grants and loans feasibility studies, exploration drilling projects, and EPC projects dealing with the construction of surface steam gathering systems and geothermal power plants, which may eventually be supplied by Japan manufacturers.

JICA's assistance strategy for the geothermal sector is focused on both technical assistance for capacity development and financial assistance through grants and/or ODA loans with favourable terms. As for technical assistance, JICA focuses on capacity development to improve various aspects of geothermal development, including the success rate of exploratory drillings and the accuracy needed for the evaluation of geothermal reservoirs. JICA's six activities for mitigating risks and removing barriers associated with geothermal development are (Wakamatsu et al., 2020):

(1) Geothermal development policy and master planning to prioritize potential geothermal development sites in a country. JICA also provides technical advice to promote public-private-partnerships (PPP) and stimulate private investment (example: Indonesia, **Kenya**, Peru, **Ethiopia**, **Rwanda**).

(2) Surface surveys and test drilling projects that contribute directly to identifying geothermal resources. Since 1973, JICA has assisted its partner countries to conduct 19 geothermal resource surveys (some including test well drilling) in 14 countries (Guatemala, Chile, **Kenya**, Philippines, Indonesia, Argentina, Thailand, Mexico, Turkey, China, Peru, **Ethiopia**, and **Rwanda**, in chronological order). JICA is currently supporting test well drilling in three countries (Ecuador, Nicaragua, **Djibouti**). In order for JICA to improve the success rate of test well drilling, JICA conducts rigorous surface surveys to develop conceptual models as well as test well drilling plans. Then it convenes an external advisory group made up of professors and well-experienced developers and drillers to solicit vital technical advice on selected targets and drilling plans in the target countries.

(3) Concessional yen loans for engineering services (feasibility planning), steam field development, and power plant construction projects (Philippines, Indonesia, Costa Rica, Nicaragua, Bolivia, and **Kenya**). JICA's yen loan has so far contributed to 1,230 MW of installed capacity in its client countries. That is around 17% of total installed capacity (7,000 MW) of all geothermal power in developing countries constructed after 1977 (UDI World Electric Power Plants Database, 2017). Total signed loan agreements are 407 billion yen (about 40 billion USD). JICA's yen loan is quite concessional and it can be as low as 0.01% interest, 40 years repayment period, with 10 years grace period. JICA is currently diversifying and expanding its portfolio. In the past decade it has increased its lending four-fold from 57 billion yen to 225 billion yen.

(4) Grant aid can also be provided for small scale well-head geothermal power plants (**Aluto field, Ethiopia**). It can also provide private debt and equity (Private Sector Investment Finance, PSIF), but so far there is no track record of private finance.

(5) Capacity building and human resource development to train a range of personnel related to geothermal development. There are short-term training courses of less than one year in Japan: (a) 6 months course for geothermal resource engineers, (b) 6 weeks course for drilling managers, and (c) 2 weeks course for executives. It also provides long term training for public sector officers to obtain masters and doctoral degrees in Japan. JICA also implements technical cooperation projects, sending teams of experts to develop capacities of geothermal development institutions and ministries of energy (**Kenya**, Indonesia).

(6) Joint research development in exploration technology to improve success rate of exploration and establish a monitoring system for long-term utilization of reservoirs

(El Salvador and Indonesia. Project currently being prepared in **Kenya**).

In 2010, JICA conducted a comprehensive survey spanning five countries in East Africa (Kenya, Ethiopia, Djibouti, Tanzania, and Uganda) to understand the region's geothermal potential, geothermal development policy and roadmaps, and the state of human resources and equipment in the sector. The survey, "Situation Analysis Study on Geothermal Development in Africa" (JICA, 2010), concluded with several recommendations for how JICA can assist its partner countries. Following the survey, JICA conducted similar studies in 2013 in Rwanda and Southern African countries (Malawi, Mozambique, and Zambia).

The main findings of the 2010 Situation Analysis Study on Geothermal Development in Africa were as follows (Wakamatsu, 2018):

- Governments should take a leading role in upstream development, since private companies are unlikely to participate in the development of areas where there are no exploration wells. The Kenyan government was already playing a leading role in the country's geothermal development in precisely this manner. Therefore, the Kenyan model was recommended by JICA as a paradigm of success for the rest of East Africa.
- The current number of equipment and geothermal professionals (engineers and geo-scientists) in each country were seriously lacking. In 2010, 368 geothermal professionals were employed across various institutions and by IPPs in the five countries, but 903 more were estimated necessary. Local universities were not well-equipped in terms of the capacity of lecturers to train geothermal engineers. The UNU-GTP program was popular due to its focus on providing practical skills, but the number of professionals it was able to train was limited (100 professionals in 10 years). Therefore, a regional training institution was deemed necessary. Moreover, 600 M USD worth of equipment for geo-scientific analysis, drilling, vehicles, weather stations, GIS, etc. was estimated to be necessary.

The survey made the following recommendations for JICA's cooperation in the EARS:

- JICA should take upfront development risks by undertaking initial surveys that include the drilling of several exploration wells.
- JICA should link the training programs in Japan with development projects in the trainees' countries so that they can directly utilize their skills on the job after returning to their country.

2.15 Federal Institute for Geosciences and Natural Resources (BGR)

The Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), the German Federal Institute for Geosciences and Natural Resources (https://www.bgr.bund.de/EN/Home/homepage_node_en.html) is based in Hannover, Germany. The BGR is the central geoscientific authority providing advice to the German Federal Government in all geo-relevant questions. It is subordinate to the Federal Ministry for Economic Affairs and Energy.

The BGR is committed to sustainable use of natural resources and protection of the human habitat. As a neutral institution feeling responsible for the future, BGR advises German ministries and the European Community and act as partners in industry and science. The leading motive of BGR daily work is "Improvement of Living Conditions by Sustainable Use of the Geo-Potentials".

Among its activities on Energy Resources, BGR is engaged in research and demonstration projects for deep geothermal energy development in the North German Basin. The activities of BGR are not limited to Germany, as BGR supports developing countries at their ambitions to utilise geothermal resources. Within this framework scientists of BGR have been active in several developing countries with favourable geothermal conditions. The focus of BGR work there is the geoscientific exploration with geological, geophysical and geochemical methods.

GEOTHERM Programme - Promoting the Use of Geothermal Energy

The German development cooperation has taken initiative to support partner countries in assessing geothermal resources. In 2003 BGR, on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ), started a technical cooperation programme (GEOTHERM I). In the joint setup of GEOTHERM II Programme, technical cooperation was done by BGR and financial cooperation by the German Development Bank (KfW).

The objective of the GEOTHERM programme was to promote the use of geothermal energy in partner countries by kicking off the development at promising sites and participate at the improvement of the legal and organisational framework for geothermal. The programme supported partner countries with high geothermal potential for electricity production or direct use. The aim was to minimise the risk associated with the development of geothermal resources at selected sites. Cooperation partners were governmental institutions, public or private energy suppliers as well as private companies.

Technical Cooperation: Geothermal Energy East Africa

The BGR supports partner institutions in East Africa in the exploration of selected geothermal fields as well as in the general advancement of geothermal development in a regional cooperation project.

The supra-regional geothermal energy project East Africa is the continuation of the GEOTHERM programme which started in 2003. The new initiative focuses, among other things, on providing training for technical staff of the partner institutions through joint feasibility field campaigns or short courses. This shall enable them to apply for financial support to the Geothermal Risk Mitigation Facility (GMRF) for the drilling of exploration and production wells.

Technical Cooperation: Geothermal Energy Tanzania

BGR supported Tanzania in the identification and exploration of geothermal sites and the implementation of a strategy to use geothermal energy within the national energy supply. In the framework of the national energy strategy several areas were investigated in the Northern Volcanic Province to examine if potential geothermal resources could be identified.

BGR co-operated with the Tanzania's state-owned Geothermal Development Company (TGDC) in the geothermal exploration of the Mt. Meru volcano by performing surface surveys, including geological, geophysical, petrological and geochemical surveys, for the investigation of potentially suitable sites.

2.16 KfW

KfW (https://www.kfw.de/kfw.de-2.html) is a German state-owned development bank, based in Frankfurt. Its name originally comes from Kreditanstalt für Wiederaufbau (Credit Institute for Reconstruction). It was formed in 1948 after World War II as part of the Marshall Plan. KfW Entwicklungsbank (KfW Development Bank) provides financing to governments, public enterprises and commercial banks engaged in microfinance and SME promotion in developing countries. It does so through loans close to market terms using its own resources ("promotional loans"), soft loans that blend KfW resources with support from the federal government's aid budget ("development loans"), as well as highly subsidized loans and grants, the latter two coming entirely from the federal aid budget. Different country groups are offered different financing conditions depending mainly on their per capita income. All these financing instruments are part of what is officially called development cooperation and is more commonly called "development aid".

Within German aid, the work of KfW Development Bank is called "financial cooperation" which is complemented by "technical cooperation" by GIZ (German Corporation for International Cooperation) and other public agencies. The main sectors of financial cooperation are water supply and sanitation, renewable energy and energy efficiency, as well as the development of the financial sector.

KfW Development Bank is promoting the use of the geothermal resource in the EARS by co-financing the Geothermal Risk Mitigation Facility (GRMF). This effort has been commissioned by:

- the Federal Ministry for Economic Cooperation and Development (BMZ);
- the EU via the EU-Africa Infrastructure Trust Fund (ITF);
- the Department for International Development (DFID).

In addition to that, KfW signed in July 2014 with Kenya's National Treasury a USD 110 million credit, with a grant component of up to 35% towards the development of Bogoria-Silali geothermal field. Most of the funds had to be employed for drilling and testing of 20 geothermal wells, for infrastructural development and to conduct further feasibility study in the area.

2.17 US Agency for International Development (USAID)

USAID (https://www.usaid.gov/) leads international development and humanitarian efforts to save lives, reduce poverty, strengthen democratic governance and help people progress beyond assistance. US foreign assistance has always had the twofold purpose of furthering America's interests while improving lives in the developing world. USAID carries out US foreign policy by promoting broad-scale human progress at the same time it expands stable, free societies, creates markets and trade partners for the United States, and fosters good will abroad.

USAID works in over 100 countries to:

- Promote Global Health;
- Support Global Stability;
- Provide Humanitarian Assistance;
- Catalyse Innovation and Partnership;
- Empower Women and Girls.

In 2013, **Power Africa** (https://www.usaid.gov/powerafrica) was launched by USAID, bringing together technical and legal experts, the private sector, and governments from around the world to work in partnership to increase the number of people with access to power.

Power Africa's goal is to add more than 30,000 MW of cleaner, more efficient electricity generation capacity and 60 million new home and business connections in sub-Saharan Africa. Power Africa brings together the world's top companies, political leaders, and financial institutions to help overcome Africa's energy crisis. Power Africa uses collective problem solving to enable African leaders to pave their own future.

US-East Africa Geothermal Partnership (EAGP) (https://www.usea.org/program/EAGP) is focused on Technical Assistance by Public Sector and, US Companies. The EAGP program is a public-private partnership between USAID and the US Energy Association (USEA).

EAGP was established in September 2012 to promote the development of geothermal energy resources and projects in East Africa. It also encourages and facilitates the involvement of the US. geothermal industry in the region. Supported countries are: Djibouti, Ethiopia, Kenya, Rwanda, Tanzania, and Uganda.

Core partnership activities include:

- Foster US-East African business relationship and geothermal power projects.
- Arrange US industry short-term technical advisory support to East African countries.
- Organize capacity building seminars and workshops in East Africa with US geothermal industry and institutions.
- Track information on East African geothermal resources, projects, events and opportunities.

EAGP collaborates with the private sector, regional organizations, international donors and East African institutions to identify immediate geothermal goods and services needs in the Rift Valley region. EAGP simultaneously works with US geothermal companies, experts, developers, equipment suppliers and capacity building institutions to facilitate access to opportunities in East Africa's geothermal sector.

Possible areas for technical support and collaboration include:

- Geothermal surface studies.
- Drilling capacity building and advisory support.
- Reservoir testing and modelling.
- Well-field development.
- Power plant design and installation.
- Legal and regulatory frameworks.
- Risk management.
- Project financing.
- Database management.
- Equipment supply.

To date, EAGP has supported the following projects focused on technical assistance:

- Technical assessment of a geothermal industrial park planned near the geothermal power plants of Olkaria in Naivasha, Kenya (2019).
- Development of a Geothermal Data Management System for GSE and EEP in Ethiopia (Aug. 2018).
- Training on geothermal drilling: Cementing for geothermal applications and geothermal fishing operations (Aug. 2018).
- Olkaria Reservoir Management Consultancy (June 2018).
- KenGen Best Practices Exchange on Geothermal Energy Development (2016). The EAGP established a Kenya – New Zealand Partnership between Contact Energy and Tauhara North No. 2 Trust (Tauhara) and Kenya Electricity Generating Company (KenGen) of Kenya in cooperation with USAID, Kenya Mission and Power Africa. The objective of the partnership is to share best practices in environmental and social guidelines while establishing professional relationships for KenGen to draw upon after the conclusion of the program.
- Executive Exchange to Lawrence Berkeley National Laboratory (LBNL) and KenGen Embedded Assignments for Reservoir Modelling at LBNL (2017).
- Consultancy for Technical Assistance and Capacity Building in East Africa (2016).
- Development of a Risk Mitigation Mechanism for geothermal development in East Africa (2016).
- Geothermal Law Development in Ethiopia (2015). Support to the Government of Ethiopia to create the legal and regulatory framework to support independent geothermal power generation.

2.18 US Trade and Development Agency (USTDA)

US Trade and Development Agency (USTDA) (https://www.ustda.gov/) connects America's private sector to infrastructure projects in developing and middle-income countries. USTDA accomplishes its mission by funding feasibility studies, technical assistance and pilot projects that integrate the expertise and innovation of American companies. The Agency also connects overseas buyers with US sellers through its reverse trade missions, industry conferences and workshops. Unique among federal agencies, USTDA is mandated to promote the participation of US industry in infrastructure projects at the critical early stages when design choices and technology options are being defined.

USTDA tools include:

- Feasibility Studies and Technical Assistance.
- Pilot Projects.
- Reverse Trade Missions.
- Conferences and Workshops.
- Training Grants.

Energy is USTDA's largest sector of investment, comprising three subsectors: traditional energy and power generation; electricity transmission and distribution; and **renewable energy generation**. The Agency's energy sector activities create partnerships between US companies and foreign project sponsors that support US jobs and increase the world's supply of clean energy and access to cleaner and more efficient fossil fuels. Fostering diverse projects in smart grid development, gas-fired power, refinery modernizations, coal-fired power, solar and energy storage, USTDA helps countries optimize their use of existing energy resources and make their energy markets more efficient and competitive. Using the creative approaches available to the Agency, USTDA creates unique opportunities for US suppliers of cutting-edge equipment, technologies and services.

In support of **Power Africa** US Government-led initiative, USTDA provides critical early-stage planning to spur new power generation, and transmission and distribution infrastructure. These activities support a range of energy development and deployment from power generation to grid modernization, which increase efficiency and improve access.

USTDA also leads the **US-Africa Clean Energy Finance** (US-ACEF) initiative (https://www.ustda.gov/program/us-africa-clean-energy-finance-us-acef-initiative), an interagency effort to mobilize financing for promising clean energy projects across the continent.

To date, USTDA has supported the following projects in East Africa mostly focused on technical assistance:

- USTDA awarded in Aug. 2018 a grant to TM Geothermal Operations Private Limited Company (TMGO), an Ethiopia-based company, to coordinate a feasibility study supporting development of the first 50 MW of a planned 520 MW Tulu Moye Geothermal project in the Main Ethiopian Rift. The study was conducted by a US firm, Delphos International, Ltd., which has expertise in supporting power sector development and financing from its work across 35 countries.
- USTDA signed a grant in June 2017 with Kalahari GeoEnergy Limited, a Zambian geothermal development company, for a feasibility study supporting the development of a 10-20 MW geothermal power plant in the Bwengwa River geothermal prospect. Kalahari GeoEnergy selected the California-based Geologica Geothermal Group to carry out the study, which provided technical and environmental analyses needed to advance the project.
- USTDA has co-financed in 2017 a feasibility study on utilising a specialised genset for a topping unit for high pressure geothermal wells to capture waste energy and

generate additional electricity at Olkaria, Kenya. The study evaluated the technical, commercial, financial, and environmental viability of utilizing Langson Energy Inc. 5 MW Total Flow Generator to make more efficient use of high wellhead pressure geothermal wells at Olkaria.

- USTDA announced in 2016 the partnership with Akiira Geothermal Limited to assess the viability of a 70 MW geothermal power plant northwest of Nairobi, Kenya.
- USTDA issued in March 2016 a Quote Request for a Geothermal Energy Project Desk Study for the evaluation of projects to support or improve its decision-making relative to the funding of geothermal energy projects or activities in sub-Saharan Africa. The Desk Study contract required the contractor to review up to 8 proposals for geothermal energy feasibility studies, technical assistance activities or pilot projects in sub-Saharan Africa and fully develop four funding recommendations for activities for USTDA consideration.

3 COUNTRIES STATUS

One of the main goals of the present report is to frame the state-of-the-art on the geothermal resource development in East African Countries (Eritrea, Djibouti, Ethiopia, Kenya, Uganda, Rwanda, Burundi, Tanzania and Comoros) and two Southern African countries (Malawi and Zambia).

The focus is on geothermal activities aimed at generating electric power by using either flashing or Organic Rankine Cycle (ORC) plants. Thus, direct uses of geothermal energy such spas, cooking, space heating and cooling, greenhouse heating, crop drying, aquaculture and heat for industrial processes are not addressed in the report. Direct uses represent the natural utilization of low temperature resources, but can complement the exploitation of medium and high temperature resources for electric power generation to improve the resource recovery and the project rentability.

The results of the literature survey, complemented with direct experiences in Djibouti, Ethiopia, Kenya and Tanzania, allow to draft a summary of the present status of geothermal development initiatives underway in each Country, distinguishing between: surface exploration projects; drilling exploration projects; well field development and power plant design and construction projects; exploited geothermal fields.

Before entering into the details of the country status, a few general considerations on the evolution of the energy market in Africa since 1990 might be useful, as many trends are shared by East Africa countries. The data shown below are taken from IEA's Data and statistics web page (https://www.iea.org/data-and-statistics) which allows to access energy data at world, region, or country levels, as well as for different energy sources.

Figure 36 shows the evolution of Total Primary Energy Supply (TPES) by generation source for the whole Africa from 1990 to 2017. Thus, it also includes the contribution of North Africa countries, as well as big O&G producers, like Algeria, Libya, Egypt, Nigeria, and Angola.

The figure shows that energy supply is dominated by Biofuels and waste, followed by fossil fuels like Oil, Coal, and Natural gas. Nuclear and Renewables account for a marginal contribution. The enormous use of Biofuels is typical of many sub-Saharan countries in which a large fraction of the population still lives in the country side working on the agricultural sector. Only a limited fraction of them has access to electric energy.

From about 2002 there was a change of the TPES steady increment, in particular for Oil, Natural gas and Biofuels. The huge increment of TPES over the period is well correlated with the population increment, as the TPES per capita changed from about 0.61 toe/capita in 1990 to only 0.75 toe/capita in 2017.

Figure 37 shows the Total Final Consumption (TFC) of energy by sector which is dominated by the Residential uses, which are mostly driven by cooking in the country side using Biofuels and by lightning and cooling in the urban areas.

Figure 36. Total Primary Energy Supply (TPES) by source for Africa, from 1990 to 2017 (Source: https://www.iea.org/data-and-statistics)

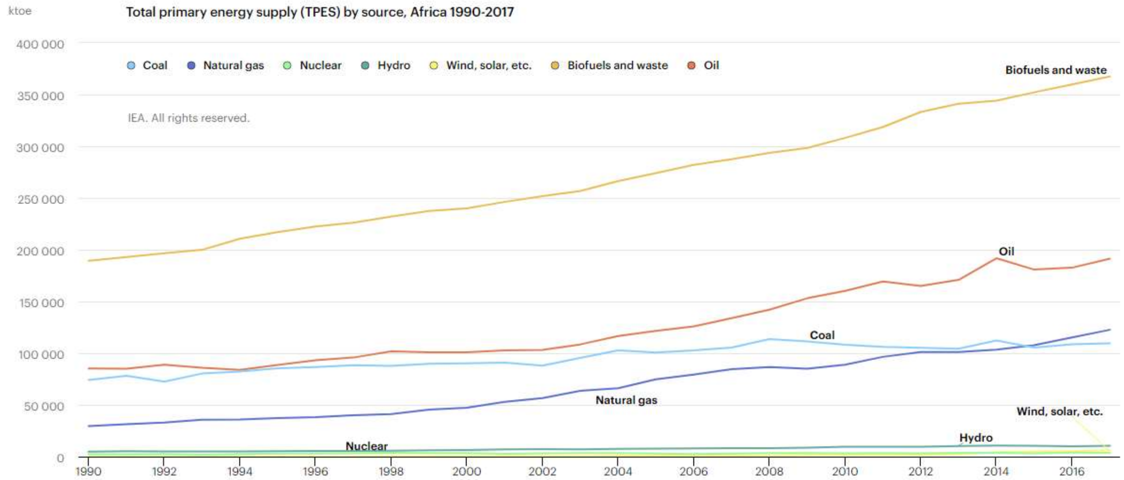
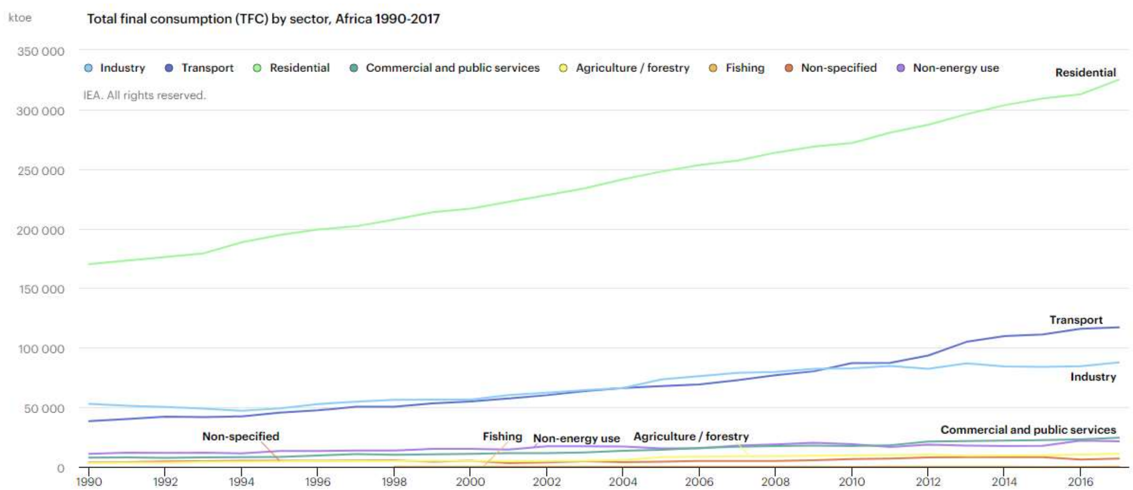


Figure 37. Total Final Consumption (TFC) by sector for Africa, from 1990 to 2017 (Source: https://www.iea.org/data-and-statistics)



Now we can have a look to the TFC by source, which is indicating the evolution of the electricity market in Africa with respect to other sources. **Figure 38** shows that the electricity was steadily increasing in the period with an acceleration around year 2002, but it still represents a minor fraction of final consumption uses dominated by Biofuels and Oil product.

This may be explained by the limited access to electricity of most sub-Saharan countries and in particular in East Africa, as shown in **Figure 39** (IEA, 2019a). In 2000 the average access rate to electricity in east Africa was around 10% of the population, remaining around 22% till 2013 to raise to about 43% in 2018.

Figure 38. Total Final Consumption (TFC) by sector for Africa, from 1990 to 2017 (Source: https://www.iea.org/data-and-statistics)

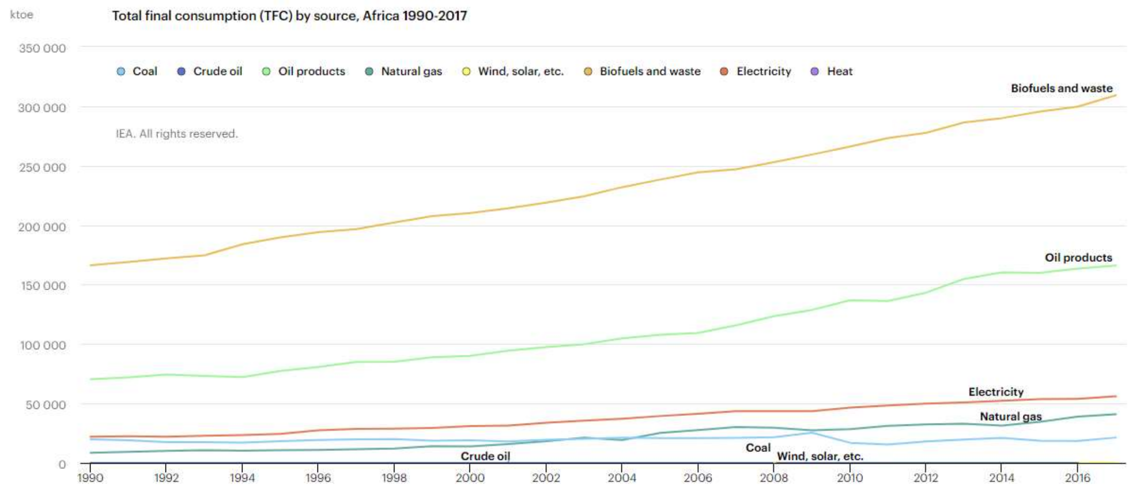
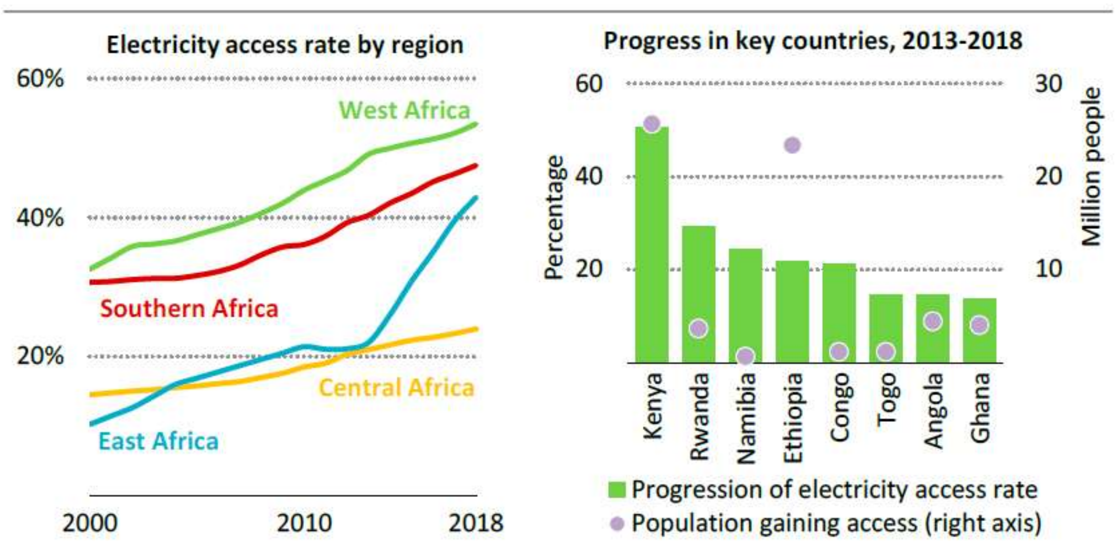
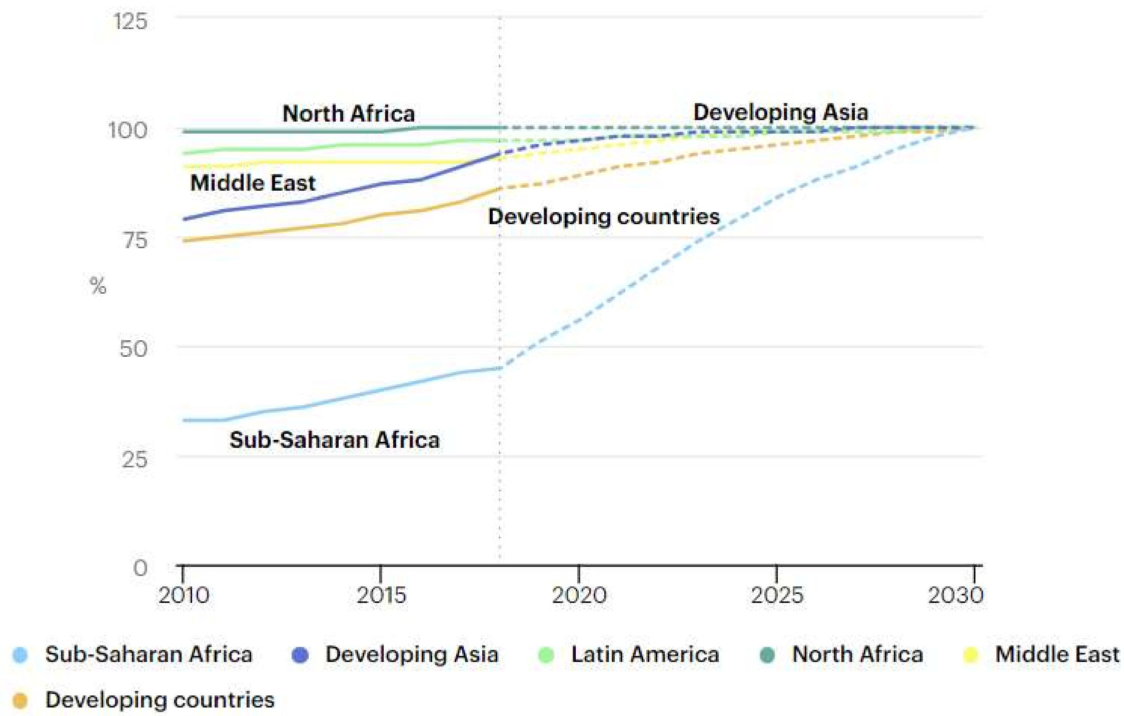


Figure 39. Electricity access progress in sub-Saharan Africa since 2000, showing an acceleration since 2013 (Source: IEA, 2019a)



As far as the expected development of electric market in sub-Saharan countries is concerned, **Figure 40** shows how the IEA Sustainable Development Scenario for the 2010-2030 period plans to increase the access rate from about 45% in 2018 to about 100% in 2030. Considering the foreseen increment of population in sub-Saharan countries and the electricity consumption dominated by residential uses, the electricity consumption is expected to have a huge increment in East Africa countries. This will drive the investments in electric power generation which will benefit also the geothermal industry in East Africa countries.

Figure 40. Access to electricity in the Sustainable Development Scenario, 2010-2030 Source: (https://www.iea.org/data-and-statistics/charts/)



3.1 Eritrea

Eritrea (The State of Eritrea) is located at the extreme North of the EARS, along the coast of Red Sea (**Figure 41**). Eritrea experienced a population growth from 1.1 M in 1950, to 3.4 M and 5.7 M in 2000 and 2019, respectively. The GDP had a steady increment from 2.12 B USD in 2010 to 6.6 B USD in 2019, thanks mainly to extraction industries and port facilities been able to attract foreign direct investment. 80% of the Eritrean workforce are still employed in subsistence agriculture. The access rate to electricity increased from 32% in 2010 to 47% in 2017.

The above figures are reflected in the evolution of TPES by source of generation shown in **Figure 42**, where energy supply till 2017 is dominated by Biofuels and Oil, which is totally imported, and by the evolution of TFC by source shown in **Figure 43**, again dominated by Biofuels and Oil. The latter is used for transport uses and to produce electricity for only 28 ktoe in 2017. The electricity consumption is extremely low, increasing from 40 kWh/capita in 1992 to 70 kWh/capita in 2017. Total installed electric power of about 158 MW (considering only power plants above 0.5 MW, being the other just small off-grid stations), has been increased to 195 MW in 2017 (Yohannes, 2020). Solar PV generation amounted to 2 GWh in 2017.

It is clear that the development of an indigenous energy resource such as geothermal energy would have clear benefits for the electric market in Eritrea depending on expensive imported fuel oil. A 50 MW geothermal power plant would already be enough to supply the base load for the present average electric energy consumption.

Figure 41. Map of Eritrea (Source: https://www.britannica.com/place/Eritrea)

Figure 42. Total Primary Energy Supply (TPES) by source for Eritrea, from 1992 to 2017 (Source: https://www.iea.org/data-and-statistics)

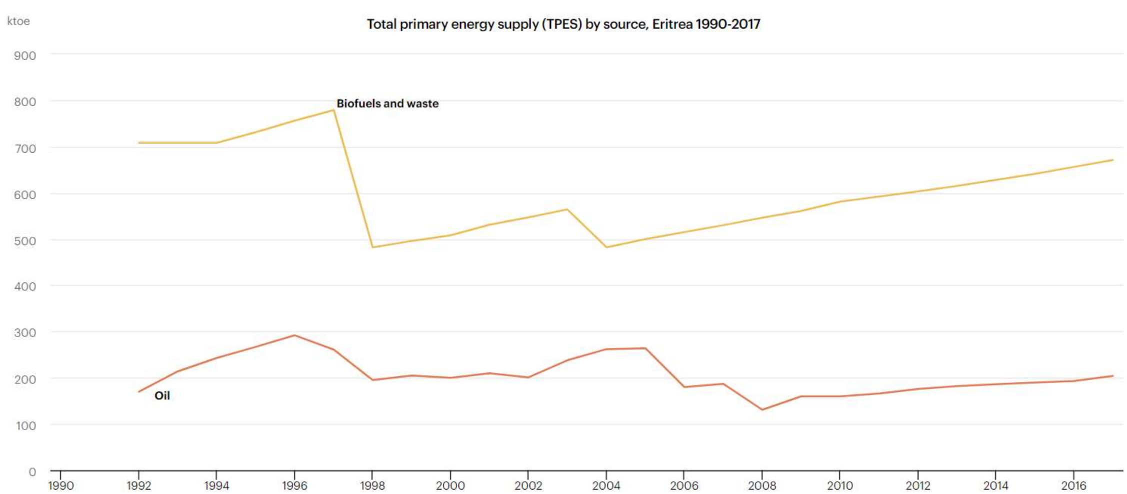
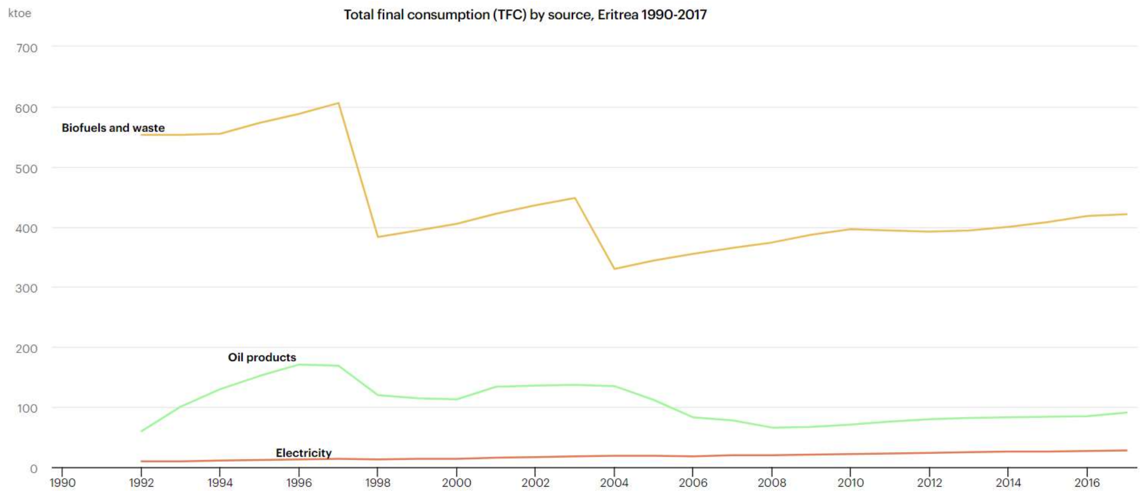
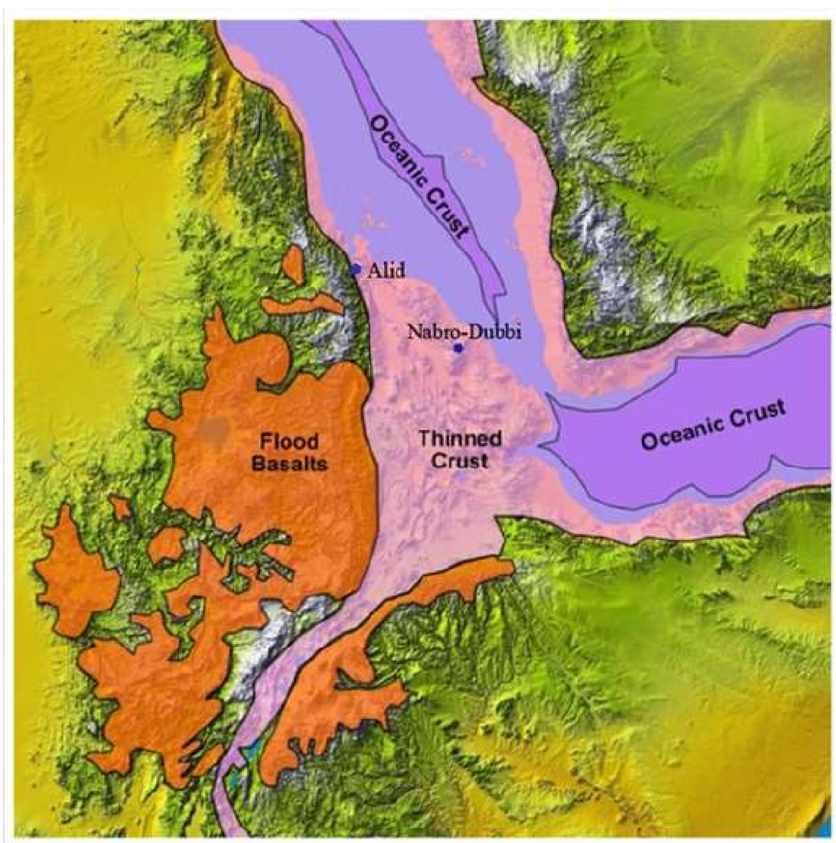


Figure 43. Total Final Consumption (TFC) by sector for Eritrea, from 1992 to 2017 (Source: https://www.iea.org/data-and-statistics)



Eritrea is located on the Northernmost end of the EARS, within the Afar region (also known as Afar or Danakil depression), a geodynamic area characterized by a thinned crust and by the Afar triple-junction where the spreading ridges that are forming the Red Sea and the Gulf of Aden emerge on land and meet the EARS, as shown in **Figure 44** (Yohannes, 2015).

Figure 44. Location map of Alid and Nabro-Dubbi geothermal prospects in relation to the East African Rift System (Source: Yohannes, 2015)



The suitable tectonic environment of the Danakil Depression subordinated by recent magmatic activities favours a high heat flow on the upper zone of the crust. Consequently, both surface manifestations of the high temperature systems associated with recent magmatism, and low temperature hot springs not related to recent magmatic activity occur in the Danakil Depression and the escarpment of the Red Sea. Surface manifestations are abundant on some of the Danakil zone mainly associated with volcanic activities of which the **Alid** and **Nabbro-Dubbi** surface geothermal manifestations are prominent.

Geothermal exploration in Eritrea commenced in 1973, when UNDP sponsored the reconnaissance survey along the EARS within Ethiopia (UNDP, 1973). The first survey located thermal springs along the Asmara-Massawa road and in the Gulf of Zula area south of Massawa. A second one was launched from the south during the same year and visited some of the fumaroles that occur on Alid volcano. In 1992, the Prof. Giorgio Marinelli and a staff member from the Ethiopian Department of Energy visited the Alid area and prepared a proposal for a detailed study. The Ethiopian Ministry of Energy and Mines refined this proposal later. This laid the basis for the geological and geochemical studies carried out subsequently in the area.

The first detailed geological and geochemical investigation work was carried out in 1996 at Alid and its surroundings by a team of USGS and the Ministry of Energy and Mines of Eritrea (MEM). The work was financed by USAID and leaded by Robert Fournier of the USGS (Clynne et al., 1996). A high temperature reservoir was inferred below the Alid volcanic centre with average estimated temperatures up to 270°C, mainly depicted by the geothermometry analysis of gas samples. The conceptual model, with liquid-dominated conditions and a boiling brine at the base, and vapor-dominated conditions above, was proposed through reinterpreting the water and gas samples of the 1996 USGS-MEM survey by Yohannes (2004).

A faults and fractures analysis was performed on the **Alid** dome in 2005 and found three structural trends that may influence the geothermal fluid path at depth (Yohannes, 2007). Based on that result, a shallow resistivity survey was conducted at a small scale from Ghinda to Darere. In 2009, an MT/TEM resistivity survey was implemented in Alid by ISOR and the Eritrean Geological Survey with the sponsorship of ICEIDA, depicting an anomaly at the rift floor (Eysteinsson et al, 2010), but failing to appropriately cover all the prospect area.

Nabro stratovolcano is the prominent volcano that occurs in a line of NE-SW direction SW of **Dubbi** volcano, collectively named as Nabro-Dubbi volcanic complex. The 2,218 m high Nabro stratovolcano is the highest volcano in the Danakil Depression. Nabro volcano itself forms part of a double caldera structure with a neighbouring volcano, Mallahle, which has a sub aerial volume of the order of 550 km^3 (Wiart et al., 2005). Trachytic lava flows and pyroclastic emplace primarily on the Nabro, followed by post caldera rhyolitic obsidian domes and basaltic lava eruptions inside the caldera and on its flanks. Some very recent lava flows were erupted along NNW trending fissures transverse to the trend of the Nabbro-Dubbi volcanic range. The 2011 eruption on Nabro has significantly sealed the old surface manifestations that occurred close to the summit. In addition, the ground at present is still very hot, making sampling of manifestations very difficult.

Dubbi is a large volcanic massif that rises to 1,625m above sea level, which erupted explosively in May 1861. The volume of lava flows alone, 3.5 km^3, makes this the largest reported historical eruption in Africa. Wiart et al. (2010) raised the issue of the potential volcanic hazards posed by Dubbi, which might concern both the local population and the maritime traffic using the strategic route of the Red Sea. Volcanic hazard represents also a main issue for any geothermal development of the area.

Table 3. *AGID -Eritrea Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/eritrea.php)*

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
Jalua	Eritrea			No	No	No
Alid	Eritrea	100		Yes	Yes	No
Nabro	Eritrea			Yes	No	No
Dubbi	Eritrea			No	No	No
Girale Dubbi	Eritrea			No	No	No

The **GEP** (**Geothermal Exploration Project**), jointly funded by the Ministry for Foreign Affairs of Iceland and the Nordic Development Fund (NDF), financed in 2013 a pre-feasibility study of the *Alid* prospect with a total budget of 1.113 M USD (GOPA, 2019). The study included a Phase 1 (geological, geochemical, gravimetric, micro seismic and topographic surveys), followed by Phase 2 (TEM & MT and hydrogeological surveys, and Social & Environmental Impact Study of geothermal development in Alid). In 2015 mapping of surface manifestation and partial gravity measurements were conducted. Unfortunately, due to hot weather conditions, all of the proposed exploration works were not finalized. The surface exploration in Alid remained incomplete at the time of the GOPA (2019) evaluation.

Despite that, the GEP expressed the willing to contribute to the identification of drilling sites in Eritrea, even though surface exploration was temporarily put on hold and not yet resumed in 2019. The project expectations are for at least 70 MW of installed capacity.

Through ARGeo, UNEP was engaged in supporting Eritrea through the Ministry of Mines and Energy in the geothermal resource development (https://www.tesfanews.net/harnessing-the-geothermal-potential-of-eritrea/, Feb. 2015), in particular in the surface exploration of Alid geothermal prospect. The goal of surface exploration was to provide information on location of target sites for drilling and minimizes the risk of unsuccessful wells. ARGeo would also assist Eritrea in preparing a proposal for the financial support from the GRMF for subsequent drilling. But after the completion of the 5th Application Round of GRMF no projects were still financed in Eritrea.

A national energy plan for Eritrea was signed in 2016 within the framework of the European Union's 11th European Development Fund (EDF) (https://www.thinkgeoenergy.com/eritrea-receives-9-million-in-eu-funding-for-geothermal-exploration-work/). As part of that, Eritrea had to receive up to EUR 175 million for investment in the energy sector, including redoing the national power grid, building stand-alone photovoltaic and wind power supply systems in rural areas and the exploration of geothermal resources.

Within the same plan, Eritrea received also funding for preliminary studies and an exploration phase at Alid geothermal prospect, which in 2016 was expected to be completed by 2020. Funds available for this project were 8 M Euro.

No papers about the status of geothermal exploration in Eritrea were found after 2015 looking at GRC library, IGA Geothermal data Base, Elsevier Science Direct, ARGeo African Rift Geothermal Conferences, and Google Scholar. Nor news were found on GRC News and ThinkGeoEnergy web sites, as well on the WWW in general. Thus, it was not possible to verify which is the actual status of the envisaged project dealing with the further exploration of the Alid prospect. From available info, it is possible to state that Alid prospect is still at a surface exploration stage, while Nabro & Dubbi prospects still are at a reconnaissance stage as shown in Table 1/5.1. No activities are documented for the other sites listed in the same table.

The AGID data bank of ARGeo reports about the national organizations active on the geothermal development in Eritrea, as shown in **Table 4**. EEC is the electric power utility which would produce and distribute the electric energy, GSE is the geological survey in charge of exploration activities, while the Geological Survey Division of MEM is in charge of the planning of geothermal sector development.

Table 4. AGID -Eritrea Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/eritrea.php)

Organization	Country	Name	Status
EEC-Eritrea	Eritrea	Eritrea Electric Corporation	Active
GSE-Eritrea	Eritrea	Geological Survey of Eritrea	Active
MEM-GSD	Eritrea	MEM Gelogical Survey Division	Active

It can be concluded that the discontinuous efforts of national and international organizations over the last 25 years were not yet able to complete the surface exploration of the Alid prospect at a level suitable to decide about the subsequent step of deep exploration drilling.

3.2 Djibouti

Djibouti (The Republic of Djibouti) is located at the north end of the EARS within the Afar Depression and is crossed by the Gulf of Aden ocean ridge (**Figure 45**). Djibouti experienced a population growth from 62 k in 1950, to 718 k and 973 k in 2000 and 2019, respectively. The GDP rose from 0.55 B USD in 2000 to 1.13 and 2.05 B USD in 2010 and 2019. About 22% of the people live in the extreme arid areas in the country side being mainly employed in nomadic cattle breeding. The access rate to electricity was fairly stable at 55-56% till 2013 to increase afterward to reach 60.2% in 2017. (https://www.macrotrends.net/countries/DJI/djibouti/electricity-access-statistics).

The TPES by source of generation (**Figure 46**) shows an increasing role of Oil and oil products (totally imported) from year 2000 to 2008 (IEA, 2010) and a corresponding reduction of Biomass at 32% in 2008, a quite low fraction with respect to most of the other East African countries. The above figures depend on the fact that about two third of the inhabitants live in Djibouti city and that because of the arid climate, Biomass resources are rather scarce. The electricity consumption was about 394 kWh/capita in 2009, higher than East Africa average, and was 472 kWh in 2016. At present, installed electric power is about 123 MW all provided by thermal plants, but for 0.3 MW Solar PV plant. Electric energy is also imported from Ethiopia thanks to the interconnection completed in 2011, for an annual average potential of 42 MW (Abdillahi et al., 2016). Consumption over the year is highly variable, as national grid demand is about 4 times greater in summer than in winter due to air conditioning.

EDD (Electricité de Djibouti) has 4 independent electrical operating systems and an electrical interconnection line with Ethiopia (https://www.edd.dj/):

- 2 main systems for Djibouti city for a total installed power of 113 MW supplied by Boulaos (90%) and Marabout (10%) power plants;
- 2 secondary systems for a total installed power of 10 MW: Subdivision South (Ali-Sabieh and Dhikil) and Subdivision Nord (Tadjoura and Obock);
- 1 electrical interconnection line with Ethiopia, since May 2011, with a total import

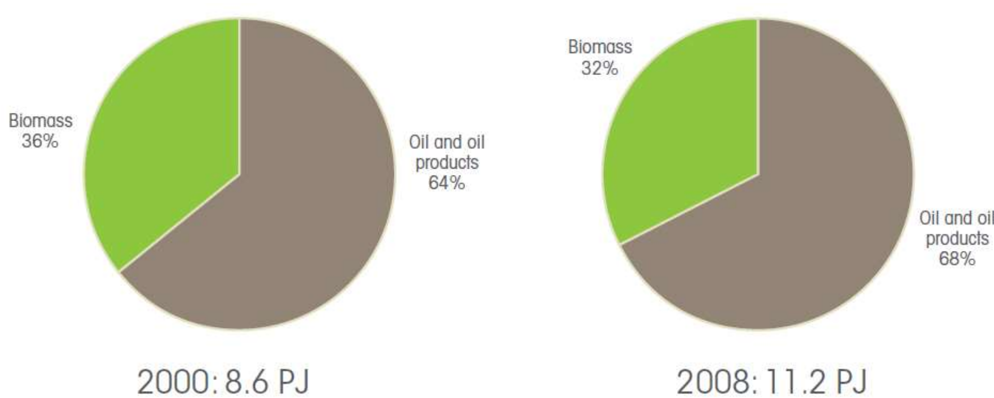
capacity of 315 MW.

Djibouti has no fossil energy resources nor hydropower, but has a high potential for solar energy, wind and geothermal resources.

The installation of wind turbines in the gran Barah for a total capacity of 2 MW is planned to supply Ali-Sabieh-Dikhil network within a WB funded project. Preliminary studies also suggest that that Ghoubet area at the end of the Gulf of Tadjoura has wind potential. There is high potential for solar energy exploitation as country global horizontal irradiation levels range between 2,000 and 2,300 kWh/(m^2 y). The Government of Djibouti (GoD) intends to use solar PV to extend electricity to the rural population. Geothermal energy potential in Djibouti was estimated between 800 and 1,000 MW based on very preliminary calculations (Abdillahi et al., 2016) whose reliability shall be further assessed.

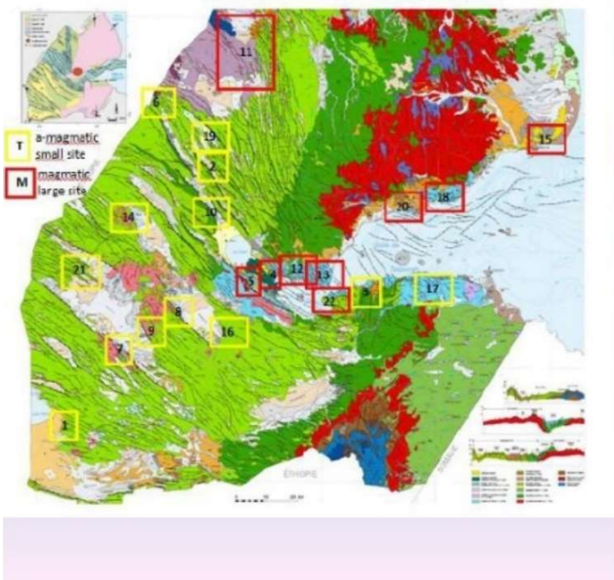
Figure 45. Map of Djibouti (Source: https://www.britannica.com/place/Djibouti)

Figure 46. Total Primary Energy Supply (TPES) by source for Djibouti, in 2000 and 2008 (excluding electricity trade) (Source: IRENA, 2010)



By the geological point of view, Djibouti is located in the Afar depression which is the result of a triple junction of three rifts: the continental East African Rift System, the Gulf of Aden and Red Sea oceanic rifts. Such a particular geodynamical situation in principle gives the area a remarkable position for the development of the geothermal energy. The surface expression of underground heat sources is related to numerous hot springs and fumaroles which are mainly distributed on the Western part of the country and along the Gulf of Tadjoura ridge. In spite of the significant geothermal studies and the deep drilling explorations conducted over the years since 1970, geothermal energy in Djibouti is still to be developed as no power plant has been built. In Djibouti 22 geothermal sites have been identified by reconnaissance and surface studies. Their location is shown in **Figure 47**. The most studied geothermal prospects and the exploration activities performed are briefly discussed here below.

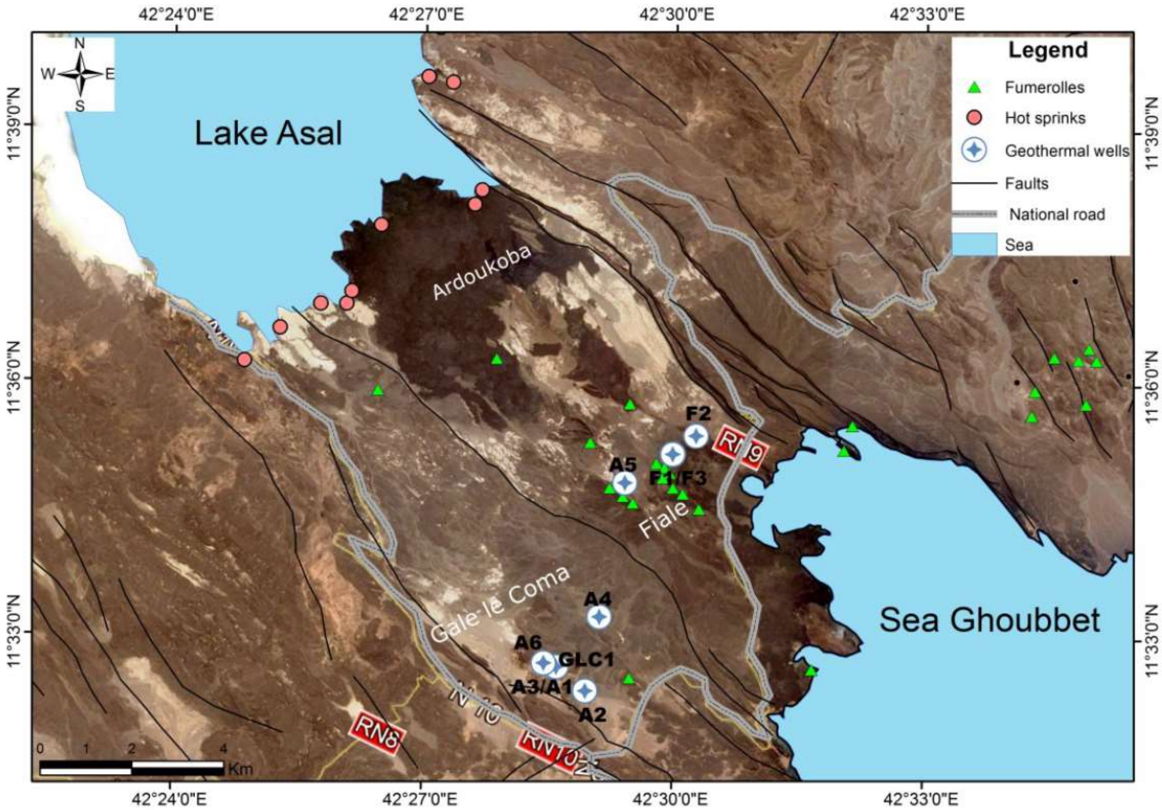
Figure 47. Location of known geothermal sites in Djibouti (Source: Awaleh et al., 2020)



Geothermal sites	
1. Lake Abhe	12. Nord Ghoubbet (Afaî-Bolli Daar)
2. Sakalol	13. NE Ghoubet (Assa Foo)
3. Arta	14. Modayto (N Gaggade)
4. Asal Fialé	15. Obock
5. Asal gale-le-koma	16. Okililaeou (SE Gaggade)
6. Balho	17. PK 20-Ambado
7. Daggadé (W hanlé)	18. Roueli
8. Dimbir-Didir (W Gaggade)	19. Sakalol
9. Garabayyis (E Hanlé)	20. Tadjoura
10. Karapti-san	21. Agna-Galafi (NW Hanlé)
11. Manda Inakir	22. Sud Est Ghoubbet

Asal Rift geothermal area. The Asal geothermal field is located in the Asal-Ghoubet rift which extends from the Ghoubet to the Asal Lake, a salt lake with level at about -155 m asl (**Figure 48**). This area is the most explored geothermal prospect in the country. Surface exploration was undertaken in the 70s by the French Geological Survey (BRGM), leading to the drilling of the first geothermal wells in the country (Asal 1 and Asal 2) which discovered a high enthalpy, highly saline geothermal reservoir on the W flank of the Asal Rift, in the area known as Gale Le Koma. Under the multi-donor Djibouti Geothermal Project with the supervision of the Italian company Aquater SpA, 3 additional wells (Asal 3, 4 and 6) were drilled in the same area in 1987-1988, while well Asal 5 was drilled in the middle of the Asal Rift (Aquater, 1989; Battistelli et al., 1991). Due to the scaling nature of the high salinity brine discharged by wells Asal 3 and Asal 6 (260-280°C, 116,000 ppm TDS), the development of the reservoir was not deemed feasible with the technology available at the time (Virkir-Orkint, 1990).

Figure 48. Structural map of Asal Rift showing surface manifestations (hot spring located on the shores of Asal lake and the fumaroles in the central part of Asal Rift and to the ENE on North Ghoubet) and location of the geothermal wells (Source: Aden et al., 2020)



Further surface studies suggested that the Fialé caldera within the Asal Rift might be a better geothermal prospect resource with fluids of lower salinity. In 2008 geophysical measurements carried out confirmed the presence of geothermal resource in the Fialé caldera. A first drilling exploration project in Fialé managed by the Icelandic company Reykjavik Energy Invest was cancelled due to the economic crisis in 2008. In 2011, the GoD committed to perform a drilling exploration project in Fialé with the financing by a group of public banks led by the World Bank. The objective of the project was to characterize the geothermal resource in Fialé and proceed with the technical and financial feasibility of the Asal-Fialé geothermal resource for large scale (50 MW) power generation, by drilling three full size directional production wells at depth of 2,500 m in a reservoir with fractured volcanic rocks where the water temperature was estimated at 300°C.

Three full-size production wells (Fialé 1, 2 and 3 shown in **Figure 48**) have been completed in 2018-19 as planned at depths ranging from 2,660 to 2,745 meters (African Development Fund, 2019). The preliminary results of injectivity tests and preliminary production tests in Fialé 1 and Fialé 2 indicated the existence of high temperatures (360°C static temperature) and moderate permeability, with high enthalpy and low productivity. A potential of 2-3 MW has been estimated for well Fialè 1. Well Fialé 3 showed a maximum static temperature of 390°C but lack of permeability.

Production tests are expected to be performed until April 2020 (ADF, 2019; World Bank (2020) to assess the potential of the geothermal reservoir to generate electricity commercially. The production tests will be followed by the feasibility study and the preparation of Bidding Documents for IPP.

Asal -Gale Le Koma geothermal field. Since June 2016, ODDEG undertook intensive field activities in the Asal rift in the area called Gale Le Koma (**Figure 48**) where wells Asal 1, 3 and 6 encountered a shallow geothermal reservoir at about 400 – 600 m depth with temperature in the order of 130-140°C, static level below about 200 m depth and a salinity in the order of 50,000 ppm, that was crossed during drilling in the '80s but was not properly characterised (Aquater, 1989). In this context ODDEG elaborated a drilling exploration program with the purpose of identifying the characteristics of the shallow reservoir. The program was financed exclusively by the government of Djibouti with ODDEG as the executing agency. The final goal was to carry out production tests for evaluating the potential of the shallow reservoir, conduct a feasibility study and then look for the financing of the installation of a 15 MW ORC plant with 3 modular units of 5 MW each.

ODDEG with the associated Turkish company PARS drilled in 2016 the shallow well GLC-1 close to well Asal 3 to a final depth of 543 m, lower than the planned depth of 700 m. The well was drilled with the Failing CF-2000 rig donated by the Turkish Government with a 40-ton capacity. The static water level was recorded at 240 m depth and a total circulation loss was encountered during drilling at 463 m inside a rhyolitic layer beneath the clay cap rock found between 375 and 421 m (Miguil, 2017). A maximum recorded temperature of 127°C at 490 m depth is reported (Aden et al., 2018), but it seems likely that the measurement was taken at non stabilised conditions. No results about the well testing of GLC-1 have been published.

The Government of Djibouti received subsequently in 2018 the financial support from Kuwait Fund for Arab Economic Development (KFAED) and Arab Fund for Economic and Social Development (AFESD) for the development of a 15 MW Geothermal Power Plant at Asal – Gale le Koma focused on drilling into the shallow reservoir where salinity is expected to be significantly lower than that of deeper reservoir. The first phase of the project foreseen the drilling and testing of up to 8 production wells and 2 reinjection wells to explore for geothermal resources in the depth interval 400 – 1,200 m. Wells had to be drilled with a new fully equipped drilling rig with 250-ton capacity purchased for geothermal exploration by the GoD. No updated public info on the project is available.

North - Ghoubet Geothermal field. The North–Ghoubet geothermal prospect is located to the ENE of the Asal Rift (**Figure 48**). The area is limited to the north by the Goda mountains and by the Ghoubet gulf (westernmost extension of the Aden ridge) in the southern part. Gravimetric measurements were done by BRGM in 1983 and lead to the discovery of heavy anomalies in different points delimited by the linear trend associated to the tectonic activity zone. Geophysical measurements were also done at the same time by BRGM, revealing three main zones: the southern Asal rift, the northern part where heavy gravity anomalies were identified, and the central part along the trend NW-SE.

To fulfil the previous surveys, the Djibouti Center for Studies and Research (CERD) started an exploration study in 2010 by completing 30 MT soundings and 26 TDEM stations. The geophysical measurements show that there is a conductive surface in the upper layer but in the deeper zone, at 1000 m bsl, a heterogeneous surface is found, with some conductive anomalies which may be associated with hydrothermal fluids. Below the horst of Moudoueoud, the MT measurements confirmed low resistivity at depth. The geothermometric study of surface manifestation fluids gives a temperature range of 170°C to 220 °C for the geothermal reservoir. The fluid chemistry suggests low salinity of the reservoir fluid compared to the Asal field, with a bicarbonate signature. This is in coherence with the geological context showing possible recharge of the system by the rainwater from the Goda Mountain through intense faulting and detrital material accumulated at the foot of the 2,000 m escarpment under the Gulf basalts (Varet, 2012). The intrusion of seawater should also account for the reservoir feeding in this faulted environment.

This study has enabled the development of a conceptual model of the geothermal system to delineate a prospective area for exploration drilling around the horst of Moudoueoud and directional wells targeting. ODDEG is preparing a new field campaign in order to complete the investigation to the E and S until the sea shore over the whole North Ghoubet area, implying geological, mineralogical and structural investigation, with more attention paid on surface hydrothermal leakages along faults. These will be completed by supplementary geochemical and geophysical surveys in order to acquire a broader view of this eventually important low-salinity geothermal system.

Arta prospect (http://www.oddeg.dj/projet-arta-grmf/). The Arta site is located on a wide valley located on the Gulf of Tadjoura, about 30 km east of Djibouti city. In 1982 Geotermica Italiana conducted geological mapping, a vertical electromagnetic survey and a gravity survey, identified a fumarole, and analyzed 15 water samples. In 2014, JICA performed a satellite image analysis, XRF rock analysis, XRD clay analysis and a fumarole analysis. A broad regional alteration and a dominant fracture system NNE - SSW was confirmed. The Arta prospect was selected as one of the four priority geothermal sites for development in Djibouti by ODDEG. The prospect is inferred to have a high temperature deep circulation system hosted by extensional and transverse fault structures.

The GoD received 1 M USD grant from GRMF in 2017, under the 3rd Application Round with ODDEG as implementing agency, for a surface exploration study of Arta prospect to be conducted by Nippon Koei-JICA Japanese consultants. The surface study performed in 2018 included the following components:

- Geology;
- Geophysics (gravity and MT/TEM surveys);
- Soil temperature survey;
- Socio-environmental scoping and pre-assessment.

The main project goals were to: prepare the conceptual model of the geothermal system; evaluate the geothermal resource potential; decide drilling targets; design exploration wells and drilling program. No updated public info on the overall project results is available.

Lac Abhé Prospect (http://www.oddeg.dj/projet-lac-abhé/). The Lac Abhé site is located in the SW of the country at the boundary with Ethiopia. The area is characterised mainly by stratoid basalts outcrops bounded by EW faults. Surface hydrothermal manifestations are numerous around the Abhe lake, with fumaroles, hot springs and many travertine deposits. Surface exploration studies including geologic and geochemical surveys have been carried out by BRGM (1970-1975), CERD (2012) and JICA (2014).

A new geothermal surface exploration study was carried out in Abhé Lake in 2015 by ÍSOR and ODDEG as part of a project funded by the Icelandic International Development Agency (ICEIDA) and the Nordic Development Fund (NDF). The study suggests the presence of a low enthalpy geothermal system with reservoir temperature of 110–150°C (ODDEG-ISOR, 2016) and a potential of about 14.5 MW (P50) estimated using the volumetric method, which might be suitable for electric power generation using an ORC plant (Cheik, 2018).

Hanlé - Garabbayis prospect (http://www.oddeg.dj/projet-hanle-garrabayis/). The Hanle - Garabbayis site is located about 110 km from Djibouti city. Alluvial and / or marine lakes deposits cover the Hanlé plain, above the Afar Stratoid Series basalt. Several thermal manifestations (fumaroles, hydrothermal alterations, steam, hot soils) are observed along the NW-SE faults limiting the Babst Alou horst and the grabens of Hanlé and Gaggadé. Transverse faults (NNE-SSW) are believed to represent the path for the up-flow of geothermal fluids in a fault-controlled system in the absence of an active magmatic heat source.

After surface studies performed in the Hanlè and Gaggadè plains, and the drilling of 3 gradient boreholes and 2 deep wells in the 80s (Aquater, 1989), new multidisciplinary studies including geophysics, geochemistry and geology were carried out by JICA in 2014-15 in the Hanlé - Garabbayis prospect (JICA, 2015a). A zone of high resistivity was found below the main surface manifestations, being interpreted as a possible high temperature zone linked to an intrusive body of basaltic rocks. According to geochemical studies, deep temperature of fumarolic gas in the order of 180°C and 260° were inferred in Goros and Garabbayis, respectively. Taking into account surface manifestation, the developed geothermal conceptual model and accessibility, five places were proposed as candidate drilling targets for deep exploratory wells (Youssouf and Hosoda, 2020).

Other prospects that have been the subject of reconnaissance studies and limited surface exploration surveys are: Ambado-PK20 (Awaleh et al., 2020); Manda-Inakir (Ahmed, 2020); Obock (Awaleh et al., 2015); Sakalol-Harralol (Awaleh et al., 2017). The AGID data base lists all the geothermal sites identified in Djibouti (**Table 5**).

Table 5. AGID -Djibouti Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/djibouti.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
ABHE	Djibouti			Yes	Yes	No
ASSAL RIFT	Djibouti			Yes	Yes	Yes
Dagadde (W Hanle)	Djibouti			Yes	Yes	Yes
GABILEMA	Djibouti			No	No	No
OBOCK	Djibouti			Yes	Yes	No
TAMATTAKO	Djibouti			No	No	No
GAGGADE	Djibouti			Yes	Yes	No
INAKIR	Djibouti			No	No	No
ALOL	Djibouti			Yes	Yes	No
N-Ghoubbet (Afai-Bolli Daar)	Djibouti			Yes	Yes	No
ARTA	Djibouti			Yes	Yes	No
S.GHOUBET	Djibouti			No	No	No
Asal Fiale	Djibouti			Yes	Yes	Yes
Asal Galei Koma	Djibouti			Yes	Yes	Yes
Balho	Djibouti					
Garabayyis (E Hanle)	Djibouti			Yes	Yes	Yes
Dimbir-Dirdir (W Gaggade)	Djibouti					
Karapti-San	Djibouti					
Manda Inakir	Djibouti					
N-E Ghoubbet (Assa Foo)	Djibouti			Yes	Yes	No
Modayto (N Gaggade)	Djibouti					
Okililaeou (SE Gaggade)	Djibouti					
PK20	Djibouti					
Roueli	Djibouti					
Sakalol	Djibouti					
Tadjoura	Djibouti					
Agna-Galafi (NW Hanle)	Djibouti					
Sud-Est Ghoubbet	Djibouti					

The AGID data bank of ARGeo reports about the national organizations active on the geothermal development in Djibouti, as shown in **Table 6**.

The Ministry of Energy and Natural Resources is in charge of the energy sector and is also the sector regulator. EDD (Electricité de Djibouti), founded on 1960, is a Public Industrial and Commercial Establishment placed under the supervision of the Government of the Republic through the Ministry of Energy, responsible for Natural Resources (https://www.edd.dj/). EDD has a legal monopoly on the transport and distribution of electrical energy throughout the national territory.

The GoD set up in January 2014 a new entity called ODDEG (Djibouti Office for Geothermal Energy Development) in charge to stimulate and ensure a rapid geothermal development (http://www.oddeg.dj/). The Djibouti Center for Studies and Research (CERD) is a public scientific and technological establishment (http://www.cerd.dj/) under the Ministry of Higher Education and Research. The CERD geothermal activities are performed by the Earth Science Institute.

Table 6. AGID -Djibouti Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/djibouti.php)

Organization	Country	Name	Status
CERD	Djibouti	Study and Research Centre of Djibouti	Active
EDD	Djibouti	Electricity of Djibouti	Active
MinE&NR-Djibouti	Djibouti	Ministry of Energy & Natural Resources	Active
ODDEG	Djibouti	Djiboutian Office for Geothermal Energy Development	Active

Almost 30 sites with surface geothermal features have been mapped in Djibouti and some 10 sites have been the subject of reconnaissance studies and detailed surface studies. Deep and shallow exploratory wells have been drilled in the Hanlé plain and in the Gale le Koma and Fialé caldera areas in the Asal Rift. Djibouti has now a dedicated institution whose mission is the development of geothermal resources of the country (ODDEG) and two drilling rigs (one for shallow and one for deep wells) which can be used for the exploration drilling plans of ODDEG, likely allowing to lower the drilling costs with respect to international drilling contractors by using its own rigs. The several surface exploration studies performed by ODDEG alone or in collaboration with foreign companies and institutions testify that considerable skills have been acquired by Djiboutian technicians, mostly in the classical fields of geosciences. All the above are promising factors for the development of country geothermal resources, considering also GoD's commitment to use the indigenous geothermal resources for the future base load of national electric network.

The deep high enthalpy, high saline reservoir found in Gale le Koma is discharging fluids with a strong scaling tendency not suitable for industrial exploitation. The characterization of the shallow reservoir found in Gale le Koma is underway. Its low temperature (130 – 140°C) and its low equivalent static level (at about 240 m depth) suggest that downhole pumping might be required in order to feed an ORC modular plant. This would increase the investment costs as well as the operating & maintenance costs of the power plant, reducing the economic feasibility of the exploitation.

Drilling at Fialé caldera found bottom temperature up to 300°C, as expected, but no info is available about the actual capacity of the 3 drilled wells. Production tests are expected to be completed within April 2020.

In conclusion, right now no geothermal prospect exists with a completed positive feasibility study that would allow to go on with field development and the EPC of the power plant. Despite the willing and efforts of the GoD to exploit the geothermal resources of the country, results achieved so far do not allow to expect that geothermal energy will be soon available to contribute to the national electric needs. On the other hand, if exploration will be finally successful, geothermal energy will be likely able to give a remarkable contribution to the limited base load requirements of national electric grid.

3.3 Ethiopia

Ethiopia (The Federal Republic of Ethiopia) is located at the north end of the EARS and includes the Afar Depression to the North and the Ethiopian Rift Valley to the South down to the border with Kenya (**Figure 49**). Ethiopia experienced a population growth from 18.1 M in 1950, to 66.2 and 112.1 in 2000 and 2019, respectively, showing an enormous increment. The GDP rose consistently from 8.2 B USD in 2000 to 29.9 and 94 B USD in 2010 and 2019. About 79% of the people live between the highlands employed in subsistence agriculture and the extreme arid areas of Afar depression and Ogaden being mainly employed in nomadic cattle breeding. The access rate to electricity was steadily increasing from 12.7% in 2000 to 44.3% in 2017. (https://www.macrotrends.net/countries/ETH/ethiopia/electricity-access-statistics).

The energy production in Ethiopia in 2017 (see Figure 2/5.3 for TPES by source in the period 1990-2017) amounted to 38,414 ktoe (https://www.iea.org/statistics/?country=ETH), with 1,114 ktoe from Hydro, 84 ktoe from Wind & Solar, 37,215 ktoe from Biofuels and Waste (mostly for domestic and agricultural uses). Importation amounted to 4,677 ktoe, of which coal for 357 kton, and oil for 4,320 ktoe (mostly for transport needs). These figures are rapidly changing in a Country in which the GDP is increasing at percentages between 5 and 10% each year.

Figure 49. Map of Ethiopia (Source: https://www.britannica.com/place/Ethiopia)

It can be seen that in 2017, 96.9% of energy production came from biofuel, actually consisting in biomass resources that include wood, animal dung, agro-industrial residue, municipal waste and bio fuels. Wood and agricultural as well as livestock residues are used mostly for cooking and heating in the country side beyond sustainable yield with negative environmental impacts (https://energypedia.info/wiki/Ethiopia_Energy_Situation#Biomass).

TPES in Ethiopia increased from 17,810 ktoe in 1990 to 41,448 ktoe in 2017. This remarkable increment was not resulting in a corresponding increment of energy consumption pro capita, as in the same period the population grew from about 47.9 M to 106.4 M, with a modest TPES variation from 0.37 toe/capita to 0.40 toe/capita. The increment of TPES has been mainly satisfied by a corresponding increment of the Biofuels and Waste component as shown in **Figure 50**. The contribution of the Hydro component is expected to increase substantially in the near future thanks to the completion of important Hydro projects, but in such a way to not reduce drastically the use of wood as the primary source of energy for residential uses in a Country in which about 79% of the population is engaged in the small-scale agricultural sector and live in rural areas. As far as the electricity production, the trend of increment changed drastically in 2009 as shown in

Figure 51, with the commissioning of new dams rising the Hydro generation from 3,524 GWh to 12,957 GWh. In 2017 the contribution of generation by Wind plants has reached a remarkable level of 862 GWh.

Figure 50. Total primary energy supply (TPES) by source in Ethiopia, period 1990-2017 (Source: https://www.iea.org/statistics/?country=ETH)

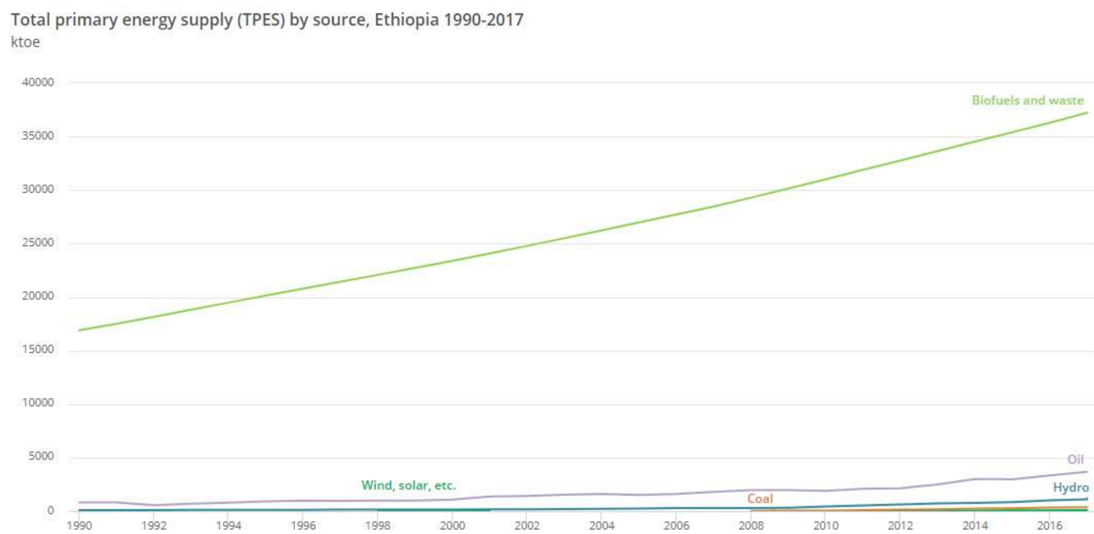
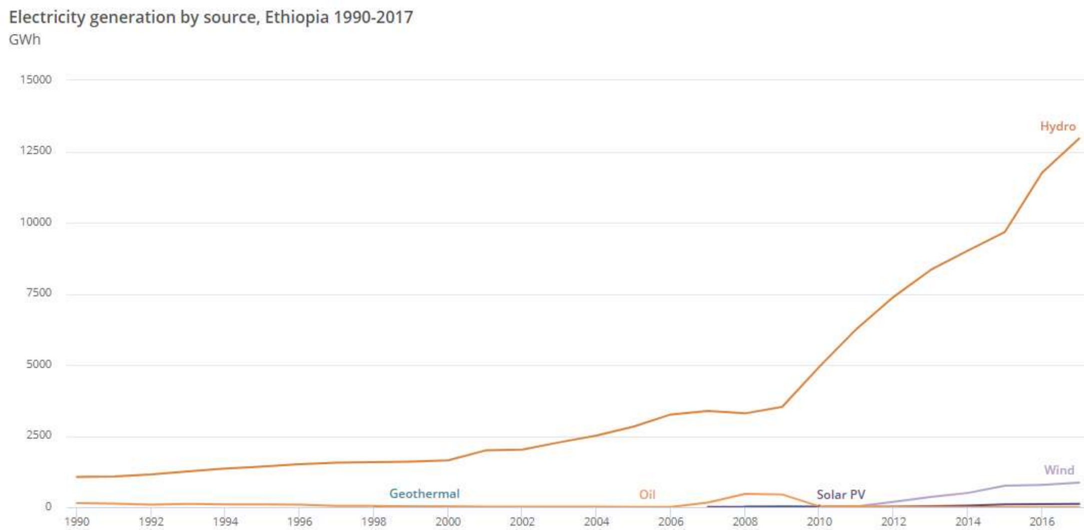


Figure 51. Electricity generation by source in Ethiopia, period 1990-2017 (Source: https://www.iea.org/statistics/ ?country=ETH)



Despite the evident progresses accomplished in particular in the last 10 years, it appears evident that due to the dynamics of population growth, there is a heavy need for increasing the domestic energy production by improving the renewable energy sources already exploited (Hydro and Wind) and developing those which are still untapped such as Solar and Geothermal. The choice to use environmentally friendly renewable resources is in line with the need to reduce the unsustainable consumption of Biomass and with the attempt to limit the import of fossil fuels from abroad, by constraining the use of Oil only to cover the energy needs of transport sector. This choice is also congruent with the decision of the Government of Ethiopia (GoE) to ratify the UN Framework Convention on Climate Change, also known as the Paris Agreement, with the Proclamation No.993/2017.

The status of installed power, where existing is roughly referred to year 2016, and the future target capacity in 2030 is shown in

Table 7, (Mekonnen, 2020). Existing capacity amounted to 4,284 MW, most of which (3,810 MW) coming from Hydro. The 7 MW of geothermal capacity refer to the combined plant at Aluto Langano field which is actually not in operation. Planned capacity expansion was estimated at 17,208 MW in 2020 and 33,080 MW in 2030. Looking at 2030 targets, most of generation capacity is expected from Hydro (20,200 MW) with strong contribution from other renewables such as Solar (3,000 MW), Wind (2,500 MW) and geothermal energy (3,500 MW). Other important contributions are expected from fossil fuels including Nuclear energy for 2,000 MW.

Such optimistic huge increment of installed geothermal capacity has actually not been reached in 2020. For instance, none of the planned 577 MW of geothermal energy will be on-line in 2020. Anyway, planned target capacities do show which are the path lines envisaged by the GoE to increase the electric generation capacity.

Table 7. Existing capacity (~ 2016) and planned production of electricity in Ethiopia at 2030 (Source: Mekonnen, 2020)

Source of Energy	Existing Capacity (MW)	(%)	Target Capacity for 2020 (MW)	Target Capacity for 2030 (MW)	Ongoing Projects (MW)	
					Under Construction	Under Preparation
Hydropower	3,810	88.94	13,817	20,200	8,804	2,280
Geothermal	7	0.16	577	3,500	70	1,000 (PPA & IA signed)
Solar	0	0	300	3,000		100 (auctioned) 450 (EOI)
Wind	324	7.56	1,224	2,500	120	Multiple Project Preparation
Nuclear	0	0	0	2,000		
Waste to Energy	25	0.58	0	300		
Other Sources	118	2.75	1,290	1,580	170	
Total	**4284**		**17,208**	**33,080**	**9,164**	**3,830**

An updated status of installed power in 2019 with expected installed power in 2020 is presented by Kebede et al. (2020) as shown in **Table 8**. Installed capacity in 2019 was 4,522 MW and that expected in 2020 is 4,742 MW, most coming from Hydro (4,077 MW). More realistically, Kebede et al. (2020) do not foreseen any contribution from geothermal energy to the installed power in 2020.

Table 8. Existing capacity (2019) and planned production of electricity in Ethiopia at 2020 (Source: Kebede et al., 2020)

	Geothermal		Fossil Fuels		Hydro		Other renewables (specify)*		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2019	7.3	58	89	460	4,077	16,245	349	1,007	4,522.3	17,770
Under construction in December 2019	70	520	-	-	10,390	30207	220	770	10,680	31497
Funds committed, but not yet under construction in December 2019	1640	8549	-	-	-	-	100	210	1740	8759
Estimated total projected use by 2020	7.3	58	89	460	4,077	16,245	569	2,164	4742.3	18, 927

*Other renewable include: wind solar and waste to energy

The significance of the actual contribution of geothermal energy to the future production of electricity in the Country depends on its estimated potential which has been periodically updated during the last two decades according to the progress of exploration activities in the country. The potential has been estimated in the range 4,200 – 10,800 MW as a result of 18 months of research and exploration by GSE and JICA (2015a) who identified 22 areas with geothermal energy development potential in Ethiopia (Kebede, 2016). This figure is recently confirmed at the upper value of 10,800 MW by Kebede et al. (2020). While this figure seems a bit optimistic considering the potential estimated in other Countries, any way it testifies that the development of geothermal resources in Ethiopia can have a non-negligible role in the future energy mix by increasing the fraction of electric energy produced from renewable resources.

Role of Geothermal energy in the Ethiopian electric sector

The commitment of the GoE towards the use of environmentally friendly renewable energies has been reaffirmed in the Geothermal Resources Development Proclamation No. 981/2016 stating that one of the Objectives of the proclamation is: *5/ encouraging a sustainable, carbon-neutral economy in Ethiopia.*

The attention of GoE towards the geothermal sector is testified by the promulgation of the Proclamation No. 981/2016, and by the recent issue on July 22, 2019, of the Geothermal Resource Development Council of Ministers Regulations No. 453/2019. The two documents intend to regulate the activities of the operators in the geothermal sector by defining the geothermal resources grade, the type of different licenses to be applied for exploration, development and exploitation, the process of license management, the rights and duties of license owners. The documents also identify the Ethiopian Energy Authority (EEA) as the Government institution in charge of the management of permitting process and of the preparation of all necessary technical directives, while the Geological survey of Ethiopia (GSE) is expected to collaborate with EEA in order to establish a process for geothermal resources data collection and management.

The present legislative framework allows both private operators as well as Government companies and/or institutions to apply for one of the three different type of licenses: i) reconnaissance, ii) exploration, and iii) geothermal well-field development and use. In particular, the Proclamation No. 981/2016 foresees the subsequent role for the GoE under its chapter *8. Government Geothermal Operations:*

> *1/ The Government may, either by itself or in partnership with other investors, undertake geothermal operations that have crucial role for the country's economic and social development.*
>
> *2/ Without prejudice to sub-article (1) of this Article the Government shall undertake geothermal resource exploration and development activities to provide sufficient data to the licensing authority to facilitate the granting of license for well-field development and use license on a competitive basis.*

The commitment of the GoE to be directly active in the valorization of the national geothermal resources is testified by the three drilling projects presently underway and managed by the Ethiopian Electric Power Co. (EEP), namely the Aluto development project and the Alalobad exploration project financed by the World Bank (WB), and the Tendaho (Dubti) exploration project jointly financed by EU and AFD. It is also worth to mention that the Aluto drilling project includes the supply to EEP of two drilling rigs complete with ancillary drilling equipment, vehicles and base camps facilities to be used for drilling at Aluto caldera (Aluto I and Bobessa prospects) as well as in future drilling projects. This choice was probably supported by the successful case history of the geothermal industry in Kenya in which two government companies, KenGen and Geothermal Development Company (GDC), had and have a fundamental role in the developing of national geothermal resources. Both companies have their own rigs managed by local personnel allowing to drill geothermal wells at competitive costs with respect to those of international drilling contractors.

At present it is not clear which business model will be chosen by the GoE for its direct intervention in the geothermal sector: i) the development of resources from exploration to the generation of electricity, as initially done by KenGen in Kenya, or ii) the exploration of the resource, and optionally the development of the well field, to subsequently transfer the license to a full geothermal operator or an Independent Power Producer (IPP), as basically done by GDC and also by KenGen in Kenya, and implicitly delineated in the above mentioned sub article 2 of article 8 of the Proclamation 981/2016. Of course, both of the above business models can coexist in the same Country, applied by distinct companies or within the same company, as done for instance by KenGen in Kenya and by Pertamina Geothermal Energy (PGE) in Indonesia.

Considering all the above, the choice of the GoE to directly promote the exploration and development of national geothermal resources is surely justified and in principle could follow what has been implemented with success in other Countries, in particular by Kenya with similar geological, economic and social conditions.

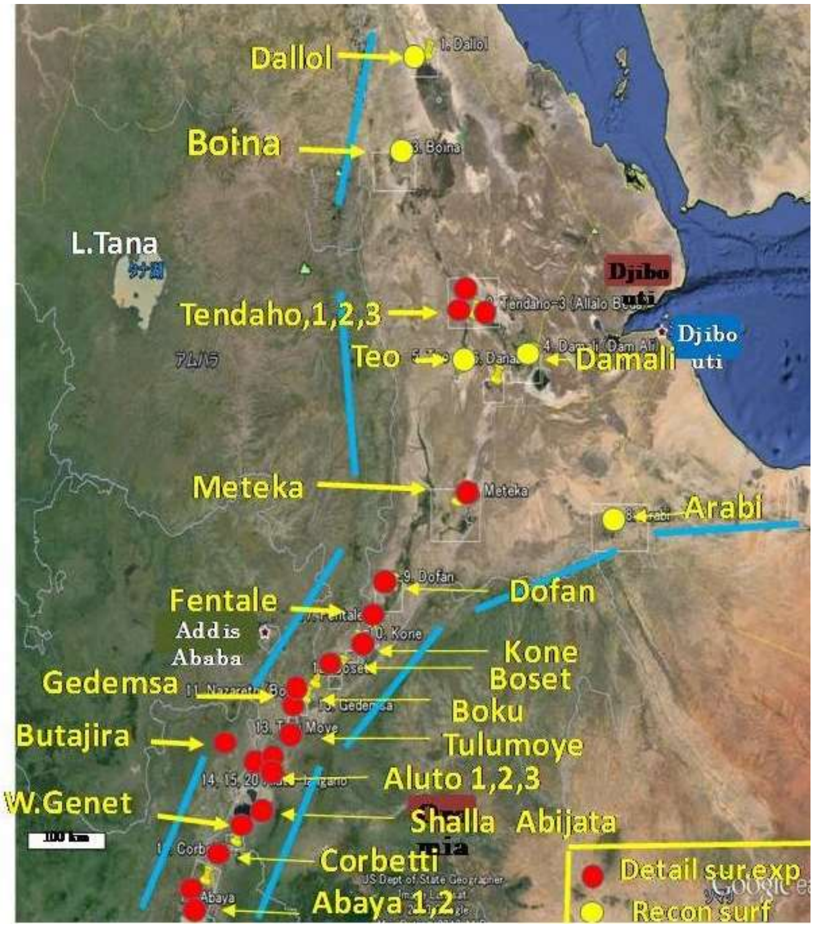
Figure 52 shows the location of identified geothermal prospects in the Afar Depression and the Ethiopian Rift Valley, distinguishing between sites identified by reconnaissance surveys only and those on which detailed surface surveys have already been performed (Kebede et al., 2020). The EARS cuts Ethiopia from NE to SW forming a topographic depression, known as the Ethiopian Rift system (

Figure 52). The Ethiopian Rift system is divided into the Main Ethiopian Rift (MER) and the Afar depression. The MER extends in a NNE-SSW trend and is dominated by occurrences of silicic volcanoes with underlying remnant magmas as heat sources. On the other hand, volcanism in the Afar depression has been mainly related to NW-SE trending fissured structural systems with some eruptive centers. The composition of the lavas produced in Afar ranges from basalt dominated to siliceous types. The lower elevations of the Rift floor are mainly filled with young sediments of Quaternary age, including conglomerate, sand, clay and lake sediments.

Ethiopia has started geothermal exploration in 1969, with a UNDP-EIGS reconnaissance study covering the whole rift system (UNDP, 1973). Under this survey, about 120 localities were analyzed and about two dozen were judged to have potential for high enthalpy resource development. A much larger number was considered to potentially host low to medium enthalpy geothermal resources suitable for direct utilizations.

Since the late 1970's, geoscientific surveys mostly comprising geology, geochemistry and geophysics, were carried out at the southern-central part of the Ethiopian Rift Valley and at Tendaho graben in central Afar (Aquater, 1980). In addition, a semi detailed surface exploration of ten sites in the central and southern Afar has been carried out in 1986 (ELC-Electroconsult, 1987). Exploration work by deep test well drilling has started during the early to mid-1980's, when exploration drilling was carried out at Aluto Langano caldera, in the southern part of the Ethiopian Rift Valley. Eight exploratory wells were drilled with four of these proving productive (ELC-Electroconsult, 1986). A power plant of 7.3 MW has been installed in 1998 using 4 production and one reinjection wells.

Figure 52. Location map of geothermal prospects in Ethiopia (detailed surface exploration and reconnaissance surveys) (Source: Kebede et al., 2020)



Further explorations in the late 90's have tested the Tendaho graben in Afar by drilling of three deep (1,811-2,196 m depth) and three shallow (about 500 m depth) wells within the Dubti prospect (Aquater, 1996; Aquater, 1998). The deepest Well TD-1 encountered a maximum temperature of 270°C but poor permeability, while the three shallow wells drilled along the inferred Dubti fault were productive, tapping a shallow liquid-dominated reservoir with temperature in the range 220-250°C (Battistelli et al., 2002).

The AGID data base provides a list of the geothermal sites identified in Ethiopia (**Table 9**).

At present, five companies hold eight geothermal licenses, as listed in **Table 10**, all awarded before the issue of the new Geothermal Resource Development Council of Ministers Regulations No. 453/2019. Only two companies have already signed the Power Purchase Agreement (PPA) and Implementation Agreement (IA): Tulu Moye Geothermal Operation Plc and Corbetti Geothermal Plc. The others are in the process of PPA negotiation and surface exploration activity (Mekonnen, 2020).

In **Table 11** the power capacity to be installed according to the existing licenses is listed, amounting to a total of 1,710 MW (Kebede et al., 2020). The total figure includes also the 70 MW development planned by EEP for the Aluto Langano field for which the licensing process is actually on-going. The location of the 8 active geothermal licenses own by private developers is shown in **Figure 53**.

Table 9. AGID -Ethiopia Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/ethiopia.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
Borawli (Northern)	Ethiopia			No	No	No
Ma'Alalta	Ethiopia			No	No	No
Debahu	Ethiopia			No	No	No
Tendaho-Ayrobera	Ethiopia			Yes	Yes	No
Dubti (Tendaho)	Ethiopia			Yes	Yes	Yes
Tendaho- Allalobeda	Ethiopia			Yes	Yes	No
Borawli (Southern)	Ethiopia			No	No	No
Teo	Ethiopia			No	No	No
Yangudi	Ethiopia			No	No	No
Gewane	Ethiopia			No	No	No
Amoissa	Ethiopia			Yes	No	No
Dofan	Ethiopia			No	No	No
Tedecha	Ethiopia			No	No	No
Boseti	Ethiopia			No	No	No
Boku	Ethiopia			No	No	No
Tulu Moye	Ethiopia			Yes	Yes	No
Alutu (Langano)	Ethiopia	500	7	Yes	Yes	Yes
Corbetti	Ethiopia			Yes	Yes	No
Duguna	Ethiopia			No	No	No
Korke	Ethiopia			No	No	No
Danab	Ethiopia			No	No	No
Fantale	Ethiopia			Yes	No	No
Gedemsa	Ethiopia			No	No	No
Abaya	Ethiopia			Yes	Yes	No
Kone	Ethiopia			No	No	No
Lake Abhe 1	Ethiopia			No	No	No
Lake Abhe 2	Ethiopia			No	No	No
Butajira	Ethiopia	0	0		exp	

Table 10. Active Geothermal License areas (awarded before the new Geothermal Resource Development Council of Ministers Regulations No. 453/2019). (Source: Mekonnen, 2020)

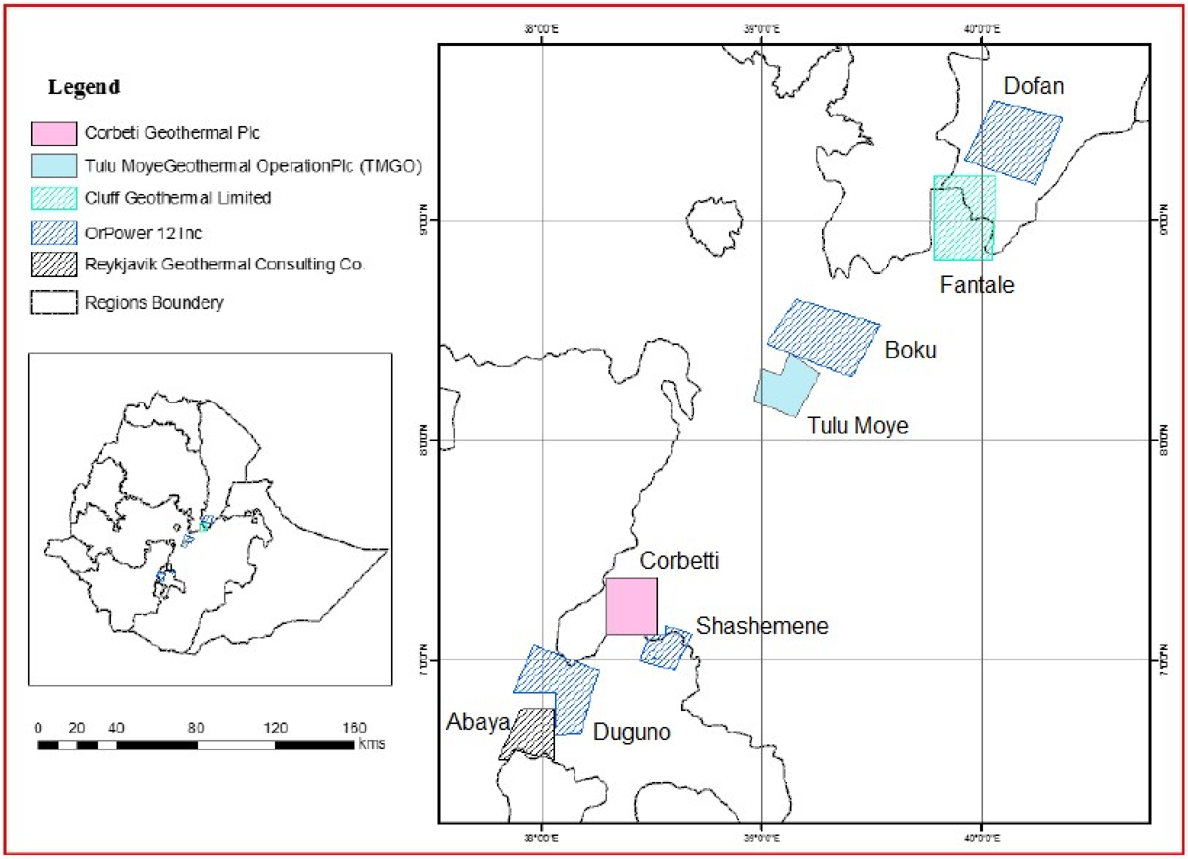
No	Company Name	Locality	Issue Date	Original Area/km^2	Remark
1	Reykjavik Geothermal Consulting Co.	Abaya	Dec. 11, 2009	513.94	Active
2	Corbetti Geothermal Plc	Corbetti	Dec. 11, 2009	735.8276	PPA & IA Signed
3	Cluff Geothermal Limited	Fentale	July 15, 2015	1,255.696	Active-PPA Negotiation
4	OrPower Twelve Inc	Boku	April 20 , 2015	342.697	Active-PPA Negotiation
5	OrPower Twelve Inc	Shashemene	April 20 , 2015	1,005.726	Active-PPA Negotiation
6	OrPower Twelve Inc	Duguno	April 20 , 2015	1249.506	Active-PPA Negotiation
7	OrPower Twelve Inc	Dofan	April 20 , 2015	1,255.65	Active-PPA Negotiation
8	Tulu Moye Geothermal Operation Plc	Tulu Moye	August 29 2018	588.3726	PPA & IA Signed

Table 11. Planned geothermal capacity to be installed according to the existing licenses (Source: Kebede et al., 2020). The licensing process for Aluto Langano is actually under way

No	Locality	Power plant name	Year commissioned	No. of units	Status[1)]	Type of unit	Total Installed Capacity MWe	Total Running Capacity MWe	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
1	Aluto Langano	Aluto Langano	1998	2	Not operating	Binary	7.3	4	-	70
2	Corbetti	-	-	-	-	-	-	-	-	520
3	Tulu Moye	-	-	-	-	-	-	-	-	520
4	Shashemene	-	-	-	-	-	-	-	-	100
5	Dofan	-	-	-	-	-	-	-	-	100
6	Boku	-	-	-	-	-	-	-	-	100
7	Dugna Fano (Abaya 2)	-	-	-	-	-	-	-	-	150
8	Fentale	-	-	-	-	-	-	-	-	150
	Total									1710

No 1 is under construction, No 2 and 3 are at financial closure, No 3 to 7 are under PPA negotiations.

Figure 53. Location of active Geothermal License areas in Ethiopia own by private developers (Source: Mekonnen, 2020).



Public Developments of geothermal resources are at present managed by EEP at Aluto Langano within the MER and at Dubti and Alalobad within the Tendaho graben in the Afar region. A summary of public developments is given here below.

Aluto-Langano Field

The exploration drilling phase of mid-'80s (wells from LA-1 to LA-8) led to the discovery of a high temperature (330°C) liquid-dominated, high CO_2 content reservoir within the Aluto caldera along fault lineaments running NNE-SSW belonging to the Wonji Fault Belt. In 1998 a combined cycle unit (with a conventional and an organic turbine) and an Ormat energy converter with a total gross capacity of 8 MW were installed being fed by four production wells, with separated liquid brine discharged in one reinjection well.

Plant operation was discontinuous due to problems linked to well production decline, scaling in production wells and brine pipelines and plant equipment failures. The Ormat energy converter was shut-down after about one and half year, while the combined cycle unit was shut-down after about 2 years. Rehabilitation was performed between 2006-07 after which the plant was again in operation before an additional stop in 2008 (http://www.gdareno.com/power/projects/aluto-langano-power-plant-rehabilitation/). The plant is at presently not working.

In 2010 a feasibility study was financed by JICA in order to plan the field development of Aluto Langano. The Ernest & Young et al. (2010) feasibility report indicated an optimal field development of 35 MW with 12 start-up wells and 7 make-up wells. On that basis, JICA funded the drilling of appraisal wells in order to update the conceptual field model and obtain new data for reservoir modeling and subsequent targeting of development wells. Drilling of two wells was carried out in 2013 - 2015 (WestJEC, 2016), by completing wells LA-9D and LA-10D to depths of 1,920 m and 1,951 m, respectively. Both wells are productive with bottom hole temperatures of over 300°C and a combined potential of about 5 MW. The WestJEC (2016) resource assessment report confirmed an optimal sustainable field development of 35 MW with 14 start-up wells and 6 make-up wells.

Further surface exploration within the Aluto caldera, funded by NDF and ICEIDA, was performed in 2015-16 with performance of geological, geochemical and geophysical surveys. The study results have indicated that there is an additional up-flow center on the caldera border, in an area referred to as Bobessa prospect to the E of the area previously drilled also known as Aluto I prospect. A conceptual model has been developed for this new area, which have indicated a potential of 35 MW (ELC-Electroconsult, 2016a).

Mostly on the basis of the Ernest & Young et al. (2010) feasibility study, the GoE and WB planned the Geothermal Sector Development Project (GSDP) consisting of four primary components, designed to better define the potential of the Aluto and Alalobad geothermal sites and to facilitate the overall development of geothermal resources in Ethiopia. These components are: (1) Aluto geothermal site development; (2) Alalobad geothermal site development; (3) Procurement of drilling rigs, associated accessories, and spare parts; and (4) Legal, institutional, and regulatory framework development (World Bank, 2014).

As far as the Aluto development is concerned, within the GSDP a contract for the supply of two drilling rigs complete with drilling accessories and base camps and for the performance of drilling services has been awarded to a Full Service Drilling Contractor (FSDC). The delivery of drilling rigs and related equipment is underway, while the drilling and testing of at least 8 wells (with provision to extend the contract up to 20 wells) in both Aluto I and Bobessa prospects is expected to start at the completion of the procurement phase in late 2020.

Since 2017, JICA is implementing a preparatory survey for a Yen Loan to support the "Aluto Langano Geothermal Power Generation Project" consisting in the construction of a geothermal power plant (capacity of 35 MW) and its related facilities (Wakamatsu et al., 2020). The project will include the design of the power plant and related facilities (such as transmission lines) based on the resource evaluation of Aluto I and Bobessa prospects whose well drillings is supported by the WB under the GSDP.

In December 2017, JICA signed an agreement with the GoE to provide up to approximately 1.8 B Yen in grant aid for the "Project for Installation of Geothermal Wellhead Power System (installed capacity of 5 MWe)" (Wakamatsu et al., 2020). Toshiba Energy Systems & Solutions Co. (Toshiba ESS) together with Toyota Tsusho Corporation and Turkish engineering company Egesim have received an EPC order issued by EEP for a Geothermal Wellhead Power System in Aluto Langano (https://www.thinkgeoenergy.com/toshiba-to-deliver-5-mw-geothermal-power-plant-to-ethiopian-electric-power/). The project is funded by the Grant Aid scheme of JICA. The Geothermal Wellhead Power System consists in a 5 MW small scale geothermal power plant to be installed in Aluto Langano field, being operated with fluid discharged by wells LA-9D and LA-10D.

Alalobad Field (Tendaho graben)

The Alalobad (or Alalobeda) geothermal prospect is located in the western margin of the Tendaho graben which is located 600 km NE of the capital city, Addis Ababa, in central Afar. In Tendaho, the first reconnaissance survey was performed by UNDP and EIGS in the early '70s (UNDP, 1973), to investigate deep structures and to delineate possible geothermal reservoirs. A geochemical survey of Alalobad surface manifestations was performed within the frame of the Tendaho Geothermal Project performed in mid '90s by Aquater SpA in collaboration with EIGS (Aquater, 1996). A radon survey made by GSE

(Teclu and Mekkonen, 2013) helped to identify the distribution of buried faults, joints and fractures. A complete surface exploration study including geological, geochemical and geophysical surveys was funded by NDF and ICEIDA and was performed in 2014-15 by ELC-Electroconsult in collaboration with GSE. The results of the surface exploration study allowed to update the conceptual model of Alalobad prospect and to propose a drilling strategy with the identification of 6 suggested well locations with 4 priority exploration wells (ELC-Electroconsult, 2016b).

Within the GSDP (World Bank, 2014), EEP is in the phase of planning the exploratory drilling operations and the construction of needed infrastructures in Alalobad. A first tender to drill and test 4 exploratory wells in Alalobad has been cancelled by EEP in March 2020 for lack of responsive proposals. The proper way to proceed with a new tender is under evaluation by both EEP and WB.

Dubti Field (Tendaho graben)

Dubti is one of the 3 prospects being studied within the Tendaho graben. The area was first studied with the reconnaissance survey performed by UNDP and EIGS in early '70s (UNDP, 1973). It was subsequently studied by Aquater SpA in collaboration with EIGS in late '70s early '80s (Aquater, 1989) with geoscience surveys covering most of the Northern Tendaho graben. Then, from 1993 to 1995, 2 deep wells and one shallow well were drilled in the Dubti area by Aquater SpA in collaboration with EIGS under a project sponsored by the Italian and Ethiopian Governments (Aquater, 1996). The project included the supply to EIGS of a fully equipped drilling rig with related ancillary equipment and instrumentation.

Well TD-1 found temperature in excess of 270°C but poor permeability within the basalts of the Afar Stratoid Series, while well TD-2 discovered a shallow liquid-dominated reservoir approx. between 220 and 500 m depth within the sedimentary sequence overlaying the Afar Stratoid series, with temperatures in the order of 220-250°C. The reservoir was subsequently tapped by the shallow well TD-4 which allowed the well logging and testing of the shallow reservoir (Aquater, 1996; Battistelli et al., 2002).

In 1996 EIGS conducted a geophysical survey at semi-detailed level over the Dubti prospect, including Schlumberger resistivity traversing, head on, gravity and VES. In 1997-98 two additional shallow wells (TD-5 and TD-6) were drilled and tested by EIGS under the supervision of Aquater SpA (Aquater, 1998). Both wells were productive and confirmed the main properties of shallow reservoir discovered by TD-2 and TD-4. In subsequent years EIGS (later becoming GSE) made several logging and testing activities on the 3 shallow wells in Dubti and additional surface surveys in the Tendaho graben.

In 2007 GSE and BGR, within the framework of the BGR GEOTHERM Programme (Geoscientific Exploration for Development of the Tendaho Geothermal System) carried out a magnetotelluric survey, that included the execution of MT and TEM stations (Kalberkamp, 2010). In 2011-2012 GSE conducted a series of integrative investigations in the Dubti and Ayrobera prospects, including 129 MT stations and detailed temperature and soil gas surveys (Bekele, 2012).

In 2013 ELC-Electroconsult performed a resource development feasibility study on behalf of GSE related to both the discovered shallow reservoir and the inferred deep reservoir in the Dubti prospect. The feasibility study suggested the development of the shallow reservoir with the drilling of 4 production and 2 reinjection wells in order to install a single-flash condensing power plant with a capacity in the order of 10-12 MW (ELC-Electroconsult, 2013; Pasqua et al., 2014), with drilling and testing services performed by a FSDC.

In July 2014, a 9 M euro loan by AFD combined with a 7.5 M euro grant from EU-Africa Infrastructure Trust Fund (ITF) were allocated to the GoE in order to develop the geothermal resource in the Dubti prospect. EEP and GSE have set two objectives for Phase

1 of the development of the Dubti prospect, considering the coexistence of an already discovered shallow reservoir and a deep inferred reservoir:

I. The delineation and the development of the shallow reservoir (down to about 600 m depth) in order to allow a sustainable exploitation with an estimated capacity of at least 10 MW.

II. The exploration of the deep inferred reservoir (down to a depth of 2,500 m) by drilling deep directional wells.

After successful completion of the first production drilling and finalization of the relevant feasibility study, Phase 2 shall consist in the EPC of a power plant of approx. 10 to 12 MW generation capacity to utilize the shallow reservoir, while additional drilling activities should be handled to develop the inferred deep reservoir whose capacity is still to be evaluated.

A first tender to drill and test 6 shallow development wells and 2 deep exploratory wells in Dubti with a FSDC approach has been cancelled by EEP in mid-2019 for lack of responsive proposals. The proper way to proceed with a new drilling tender is still under evaluation by both EEP and AFD.

Ayrobera Prospect (Tendaho graben)

Ayrobera surface manifestations are located about 6 km NNW of the Dubti field in the northern sector of Tendaho graben. The area was identified during the reconnaissance survey of UNDP and GSE (UNDP, 1973) and was afterward studied by Aquater SpA in collaboration with EIGS during the exploration of the Tendaho graben in late '70s – early '80s (Aquater, 1980) and then during the Tendaho Geothermal Project in mid '90s (Aquater, 1994; Aquater, 1996).

From 2015 to 2017, JICA in collaboration with GSE conducted a surface survey at the Ayrobera prospect, within the northern sector of Tendaho graben, under the "Data Collection Survey for Geothermal Development in Ethiopia" (Wakamatsu et al., 2020). After calculation of geothermal potential using the heat stored method, Ayrobera, with estimated geothermal potential of 25 MWe, was proposed as a suitable site for test well drilling. Survey results included also the development of conceptual reservoir model and a drilling plan for site exploration. Based on these data, JICA is now planning to support test well drilling at Ayrobera.

Private Developments of geothermal resources in Ethiopia are at presently managed by 5 different companies in 8 prospects all located within the MER, as shown in Figure 5/5.3. A summary of private development prospects is given here below, with more focus on those better documented.

Corbetti Geothermal Plc: Corbetti Caldera

The Corbetti geothermal prospect area is located about 250 km south of Addis Ababa. Corbetti is a silicic volcano system within a 12 km wide caldera that contains widespread thermal activity such as fumaroles and steam vents. EIGS conducted surface exploration surveys in the '80s including geological mapping, petrography and petrochemistry, geochemical and geophysical surveys (Altaye et al., 1986). Six temperature gradient wells were drilled by EIGS in 1987 to depths ranging from 93 to 178 m, with a maximum recorded temperature of 94°C (Kebede, 2015).

Since 2009 Corbetti Geothermal Plc is holding a geothermal license of about 736 km^2 encompassing the whole Corbetti caldera. Detailed geological, geochemical and geophysical investigations conducted in the Corbetti area indicate the presence of potential geothermal reservoirs with temperatures exceeding 250°C. The following activities have been performed: initial studies and field work; detailed geological, geochemical and geophysical surveys in close collaboration with the GSE; baseline studies and delivery of the Environmental and Social Impact Assessment and Environmental Management Plan; signing of an initial PPA and IA.

After years of stalling activities, Corbetti Geothermal and its sponsors – InfraCo Africa (a PIDG company), Berkeley Energy who manage the Africa Renewable Energy Fund, Iceland Drilling and Reykjavik Geothermal – have signed on March 31, 2020, a new PPA and IA with the GoE and EEP. The signed PPA and IA will allow the project to move into the next phase of implementation, and to commence the drilling program. (https://www.thinkgeoenergy.com/corbetti-geothermal-signs-new-ppa-and-implementing-agreement-for-project-in-ethiopia/).

Corbetti will be developed in two phases over a 5-year period. The first phase will drill 4 to 6 exploratory wells, with support from GRMF, to raise debt finance to drill a further 4 to 7 wells and build a 50 MW power plant, which is expected to become operational in 2023. The second phase will consist of an additional 100 MW power plant and facilities. Corbetti Geothermal has been awarded a grant from the 1st Application round of GRMF for the drilling of 3 full size wells at 2,000 m depth.

Tulu Moye Geothermal Operation Plc: Tulu Moye prospect

The Tulu Moye geothermal project is operated by TMGO (TM Geothermal Operations PLC, http://www.tmgeothermal.com/) a company belonging to Reykjavik Geothermal Ltd (RG), the Icelandic based Geothermal developing company, and Meridiam, a French based global investor and asset managing company. Tulu Moye concession is located in the MER, just 70 km SE of Addis Ababa, and 75 km N of the Aluto Langano field.

TMGO performed geologic, geochemical, soil gas, microseismic and geophysical surveys to develop the conceptual model of the geothermal system and identify the location of the exploration and development wells to be drilled (Guðbrandsson et al., 2020). The Tulu Moye concession bears all characteristics of hosting a high enthalpy geothermal system, being in a tectonically active segment of the EARS, displaying recent volcanic activity, with an area of over 200 km^2 of low resistivity reaching to a suitable depth for production, where a geothermal reservoir in excess of 230 °C is estimated to be found. With an investment of around 800 M USD, the project plans to build a 50 MW plant in a first phase by 2023 and reach 150 MW by 2025 (Phase 2 of 100 MW) providing power to the Ethiopian electricity grid.

TMGO awarded the drilling of 8 exploratory wells to KenGen in 2019 in order to drill for the first phase of field development (50 MW) in the spring of 2020.

TMGO has signed on March 31, 2020, an updated Power Purchase & Implementation Agreement with EEP, the Ministry of Finance and the Ministry of Water, Irrigation and Electricity to allow the Tulu Moye Project to accelerate progress and investment in Ethiopia (https://www.thinkgeoenergy.com/ adapted-ppa-and-implementation-agreement-for-tulu-moye-geothermal-project-ethiopia/). TMGO has been awarded a grant from the 2nd Application round of GRMF for surface studies including soil gas emission, MT, TDEM, proton magnetometer.

Reykjavik Geothermal Consulting Co.: Abaya prospect

The Abaya area is in the western half of the Southern Main Ethiopian Rift (SMER), which extends from Lake Hawassa and slightly past Lake Chamo, in a southwestern direction (Cervantes et al., 2020). The SMER is the youngest part of the MER and is thought to be comprised of less-evolved rifting in comparison to the Central and Northern MER. The concession is cut across by a NNE-SSW trending fault swarm and is also the setting for three prominent graben structures. Surrounding and within the license area are various volcanic centers, with what is known as the Salewa-Dore and Hako rhyolitic eruptive complex accommodating the most recent volcanic activity in the area. Most geothermal surface manifestations are found on the NW Abaya fault, a large ignimbrite escarpment on the western part of the Chewkare Graben. Manifestations consist of thermal springs, from moderate to boiling temperature, as well as steaming ground and fumarolic activity. The results of surface surveys performed strongly suggest the presence of a high-enthalpy reservoir with temperatures in excess of 230°C suitable for geothermal power production in the Abaya area.

The objective of the Geothermal Development Project in Abaya is to provide up to 300 MW of clean electric power from a renewable source to Ethiopia at a stable, cost competitive price. The project will be developed in 2 phases (VSO, 2019). The first phase includes the construction of up to 50 MW power station with turbines/generators, collection pipelines from the wells to the station, cooling system (tower), and discharge outlet. The second phase is for power expansion from 50 MW up to 300 MW.

As far as the first phase is concerned, the following activities have already been performed (VSO, 2019):

1. Reconnaissance study, overview of the potential resource. Exploration license in place. Signed PPA & IA are waiting to be approved by EEA.
2. Resource quantification, exploration and confirmation. Field reconnaissance involving geophysical and geochemical surveys.
3. Environmental and Social Impact Assessment report in accordance to the IFC Performance Standards (IFC, 2012a).

The following further activities are planned (VSO, 2019):

4. Pre-development exploration drilling in target area (1-4 wells). Development planned and assessment of the project's feasibility. Civil work for construction of roads and drill pad(s), hiring of contractor(s) for exploration drilling and water provision.
5. Drilling of development production (14-16) and reinjection (3-4) wells.
6. Power plant construction including turbine /generator and condenser.

The Abaya project has been awarded a grant from the 4th Application Round of GRMF for surface studies including geologic, geochemical, MT, TDEM, LiDAR surveys and ESIA.

Cluff Geothermal: Fantale prospect

Cluff Geothermal Limited, a geothermal exploration and development company belonging to the British company Hotspur Geothermal (https://www.hotspurgeothermal.com/about/), identified the area surrounding the Mt. Fantale volcano (also known as Fentale), a prominent stratovolcano situated within the MER approximately 200 km east of Addis Ababa, as a suitable site for geothermal exploration and power plant development. (Elliot et al., 2020) Cluff geothermal was awarded the Fantale Geothermal Exploration License in 2015.

The Fantale geothermal prospect has been the subject of considerable geothermal exploration. Earlier geoscientific studies of the area prompted the initial 1987 reconnaissance study by ELC in collaboration with EIGS (ELC-Electroconsult, 1987). Further studies were performed by GSE in the 2000s (Bekele et al., 2007). These early studies noted several features at Fantale which suggest the presence of a suitable geothermal resource. These include: a recent volcanic complex exhibiting caldera collapse and indication of a shallow heat anomaly; hot springs and surface manifestations; active tectonics; sufficient groundwater recharge; and the presence of a low permeability cap rock.

Cluff Geothermal carried out surface exploration works and analysis between 2015 – 2017 (Elliot et al., 2020), partially supported by a grant from GRMF. These included: remote sensing and geological mapping; water sampling and analysis; and a 246 station MT survey. The acquired data were interpreted and used to develop a detailed conceptual model of the geothermal system, which allowed to identify exploration drilling targets and a plan phased 400 MW field development strategy.

Each phase will provide new information to determine whether to proceed with further resource development. Given the current greenfield nature of the Fantale prospect, the Conceptual Development Plan has focused primarily on Phase 1 of the development, split into two parts: Phase 1a of 50 MW and Phase 1b of 100 MW. Phase 1a will start with exploratory drilling to confirm the presence of an exploitable geothermal resource. Phase 2 and 3 will involve additional field expansions of 100 and 150 MW, respectively.

Fantale has received funds from the 2nd Application Round of GRMF for surface studies including MT and TDEM surveys, and from the 3rd Application Round of GRMF for the drilling of 2 full size wells at 2,500-3,000 m depth.

OrPower 12 Inc. (4 prospects)

OrPower 12 Inc. is the subsidiary in Ethiopia of Ormat Technologies Inc. (https://www.ormat.com/en/renewables/geothermal/main/). OrPower 12 owns, since 2015, 4 geothermal licenses, namely Dofan, Boku, Shashemene (or Wondo Ganet), and Duguno (or Daguna Fano), whose locations are shown in Figure 8/5.3. For each license a PPA is under negotiation (Mekonnen, 2020).

Dofan prospect received funds from the 5th Application Round of GRMF for exploration drilling activities. The prospect has an inferred potential of 60 MW.

Boku prospect received funds from the 4th Application Round of GRMF for drilling activities. According to the GRMF Web GIS page, Boku prospect has an inferred potential of 70 MW. The resource is related to a Low-Enthalpy Deep Circulation system. GRMF funds were requested for 2 slim holes and 1 full diameter well at 1,600-1,700 m depth.

Shashemene (also referred to as Wondo Ganet) prospect received funds from the 4th Application Round of GRMF for drilling activities. According to the GRMF Web GIS page, Wondo Ganet has an inferred potential of 150 MW, related to a Low-Enthalpy Deep Circulation system. GRMF funds were requested for 2 slim holes and 1 full diameter well at 1,200-1,400 m depth.

Duguno (also referred to as Duguna, Daguna Fango or Dugna Fano) prospect received funds from the 4th Application Round of GRMF for drilling activities. According to the GRMF Web GIS page, Duguno has an inferred potential of 50 MW, related to a Low-Enthalpy Deep Circulation system. GRMF funds were requested for 2 slim holes and 1 full diameter well at 1,370-1,460 m depth.

Table 12 lists the main Ethiopian organizations included in the AGID data base. EEP Co (https://www.eep.com.et/en/) is the national Ethiopian electric utility in charge of power generation, transmission and sale. The GoE has assigned EEP the goal to develop Aluto Langano prospect within the MER and Dubti and Alalobad prospects in the Tendaho graben (Afar).

EEA (http://eea.gov.et) is the national Authority in charge of: issuing and administrating electric and geothermal resource development operation licenses; promote reliable and equitable electricity services; determining tariff; setting performance standards and improve energy efficiency and conservation by. As far as the geothermal operations in the country, EEA is responsible for setting the directives for the permitting process and execution of drilling and testing activities, issuing the geothermal licenses, authorize drilling programs and drilling permits, as well as to monitor the execution of drilling and testing activities. About the directives regulating the drilling of geothermal wells, EEA is making explicit reference to The African Union Code of Practice for Geothermal Drilling (AU, 2016), even though EEA is adding some more prescriptions.

GSE's (formerly EIGS) objectives cover a wide range of geoscientific studies and services such as geological and geochemical mapping, mineral exploration, groundwater studies, engineering geology and geophysics and exploration of the geothermal resources in Ethiopia. Historically, EIGS-GSE was involved in all the surface and drilling exploration projects performed in the country on behalf of the GoE. GSE has internal capabilities and equipment to perform and interpret all the geoscience surveys required in geothermal exploration, and some skilled expert for well testing and reservoir engineering.

The Ministry of Water, Irrigation and Electricity (MoWIE) is a regulatory body involved in the planning, development and management of resources, preparation and implementation of guidelines, strategies, polices, programs, and sectoral laws and regulations.

Table 12. AGID -Ethiopia Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/ethiopia.php)

Organization	Country	Name	Status
Addis Ababa University	Ethiopia	Geopysical Observatory of the University of Addis Ababa	Active
EEA	Ethiopia	Ethiopian Energy Authority	Active
EEPCO	Ethiopia	Ethiopian Electric Power Corporation	Active
GSE-Ethiopia	Ethiopia	Geological Survey of Ethiopia	Active
MoWIE-Ethiopia	Ethiopia	Ministry of Water, Irrigation and Electricity	Active

Ethiopia has important geothermal resources related to identified prospects located in the Afar Depression and the MER, amounting in the most optimistic estimates up to 10,000 MW. Electric generation from geothermal energy is planned to contribute to the increasing base load requirements of national electric grid, as a complement to the generation based on Hydro, Solar and Wind. Despite this favorable framework, at present there are no geothermal plants in operation in Ethiopia, being the only existing plant in Aluto Langano (7.3 MW installed capacity) not in operation by several years.

This situation occurs after intensive surface exploration and deep drilling in two main geothermal areas, namely Aluto Langano in the MER and Tendaho graben in the Afar Depression, conducted over more than 35 years from state institutions (EIGS, GSE, EEP) and supported by several different international stakeholders. Despite the efforts of the GoE, the full development of geothermal resources by state institutions/companies was not effective and still encounter some problems if reference is made to the drilling projects in Dubti and Alalobad, both in the Tendaho graben. At present the projects are in a stand-by stage waiting for the updating of procurement strategy after the canceling of the Full Service Drilling Contractor tender for both prospect.

Those projects, and the Aluto Langano drilling project, are all managed by EEP which is an electric utility with a large experience on Hydro projects, but a quite limited experience on the mining issues related to the development of geothermal fields. More skilled personnel and specific experiences are owned by GSE which is still performing basic surface exploration studies on several prospects but was involved till now only in a limited way in the management of the 3 drilling projects. A greater involvement of GSE and GSE's personnel could be beneficial.

Until a few years ago the interest of international operators on Ethiopian geothermal resources was limited, basically hindered by a not very clear status of the geothermal energy market in the country. While 2 licenses were active since 2009 and 5 since 2015, only surface surveys were performed, while the much more expensive deep exploration wells were not drilled in any of the active licenses so far.

Things seem to have changed substantially with the promulgation of the Proclamation No. 981/2016, and in particular by the recent issue on July 22, 2019, of the Geothermal Resource Development Council of Ministers Regulations No. 453/2019. The two documents regulate the activities of the operators in the geothermal sector by defining the geothermal resources grade, the type of different licenses to be applied for exploration, development and exploitation, the process of license management, the rights and duties of license owners. The Ethiopian Energy Authority (EEA) is identified as the Government institution in charge of the management of permitting process and of the preparation of all necessary technical directives. On May 2020 the US Energy Association (USEA) in cooperation with USAID within the Power Africa initiatives, has issued a request for proposal for CVs–Expert Advisory Task Force to assist EEA's Geothermal Directorate in its task of conducting compliance and monitoring activity, facilitating approval of permits for drilling plans, drilling programs, well design plans, drilling permits and reviewing of the regulatory aspects of Power Purchase Agreements (PPA) and Implementation Agreements (IA).

As a consequence, updated PPA and IA have been signed recently by Corbetti Geothermal for the Corbetti prospect and by TMGO for the Tulu Moye prospect, and exploration drilling at Tulu Moye started in April, 2020. It seems that geothermal resource development by international IPP might now be faster than that conducted by state owned institutions/companies.

Reconnaissance surveys, as that performed in 2014-15 by GMS in collaboration with JICA on more than 20 prospects, as well as surface exploration surveys performed by GSM, may be extremely useful to identify the most promising prospects for which exploration licenses can be awarded on a competitive basis to both national and international operators as already foreseen by the Geothermal Resource Development Regulations No. 453/2019. This approach would follow that customarily used in other countries with mature geothermal industrial markets (USA, Indonesia, Philippines, Italy, etc.).

3.4 Kenya

Kenya (The Republic of Kenya) is crossed N-S by the Kenya Rift Valley belonging to the EARS (**Figure 54**). Kenya experienced a population growth from 6.1 M in 1950, to 32.0 and 52.6 in 2000 and 2019, respectively, showing a huge increment. The GDP rose consistently from 12.7 B USD in 2000 to 40 and 89 B USD in 2010 and 2019. About 72% of the people still live in rural areas employed in subsistence agriculture and cattle breeding. The access rate to electricity was steadily increasing from 15.3% in 2000 to 43.1% in 2013, to raise at 63.8% in 2017. (https://www.macrotrends.net/countries/KEN/kenia/electricity-access-statistics).

Figure 54. Map of Kenya (Source: https://www.britannica.com/place/Kenya)

The TPES (**Figure 55**) is still dominated by Biofuels and waste (mainly wood and charcoal), used by the population in the country side and in the suburb of metropolitan area, for basic heating and cooking needs. The Biofuels consumption trend show an increment related to the population increment. The second and third contribution to TPES is given by Oil, used both for transport and electric generation in thermal plants, and by renewables which include geothermal energy, solar and wind. Minor contributions come from Hydro and Coal.

The electricity generation trend (by source) is shown in **Figure 56**. Hydro gave historically an important contribution to electric power generation, with trends reflecting the variable climatic conditions in different years. Since about 1996 Oil was increasingly used to generate electricity, but its use is declining since about 2009. Generation from geothermal resources had a first important increment in 2003 and a remarkable increment in 2013, to become in 2017 the primary source for electric generation in Kenya.

Figure 55. Total primary energy supply (TPES) by source in Kenya, period 1990-2017 (Source: https://www.iea.org/data-and-statistics)

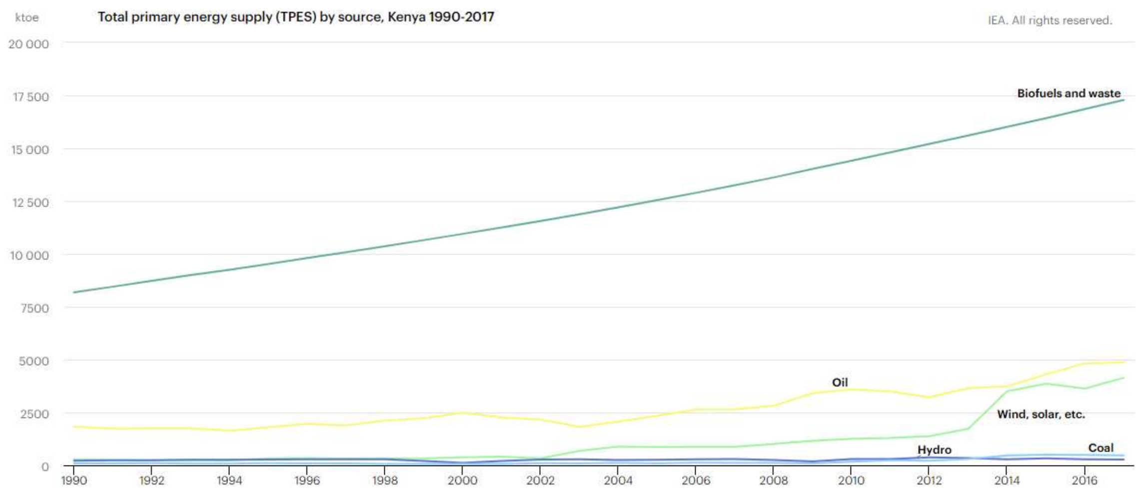
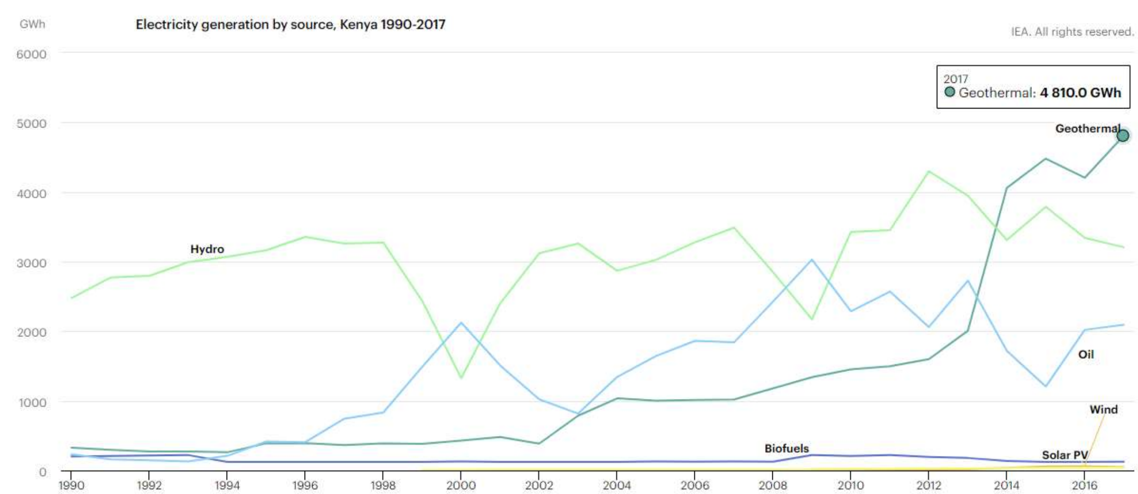


Figure 56. Electricity generation by source in Kenya, period 1990-2017 (Source: https://www.iea.org/data-and-statistics)



The interconnected installed capacity in 2018 was 2,938 MW, out of which geothermal contributed for 865.4 MW, Hydro for 837 MW, thermal for 807 MW, Solar for 92.5 MW and Wind for 336 MW. Additionally, Kenya has an off-grid installed capacity amounting to 31.1 MW comprising thermal at 26.3 MW, Wind at 0.55 MW, Solar at 0.64 MW and geothermal at 3.6 MW (Mangi, 2018; Omenda et al., 2020).

Kenya is the leading country in Africa in terms of geothermal power generation and 9th in global ranking of geothermal producing countries (Omenda et al., 2020), with an estimated potential of up to 10,000 MW (Omenda, 2018b). Kenya is currently one of the fastest growing geothermal power producers in the world having increased its production by 218 MW from 2013 to a total installed capacity of 865.4 MW in 2019, contributing to about 29% of total installed electricity capacity and about 47% of electricity consumed in 2019.

The installed geothermal capacity in 2019 comprises 706.8 MW by KenGen, 155 MW by OrPower 4 Inc. and 3.6 MW by Oserian Development Company Ltd. (Omenda et al., 2020). Olkaria geothermal field is so far the largest producing site with current installed capacity of 862.9 MW, while Eburru field has an installed capacity of 2.52 MW. Installed capacity for direct utilization of geothermal energy is about 18.5 MW.

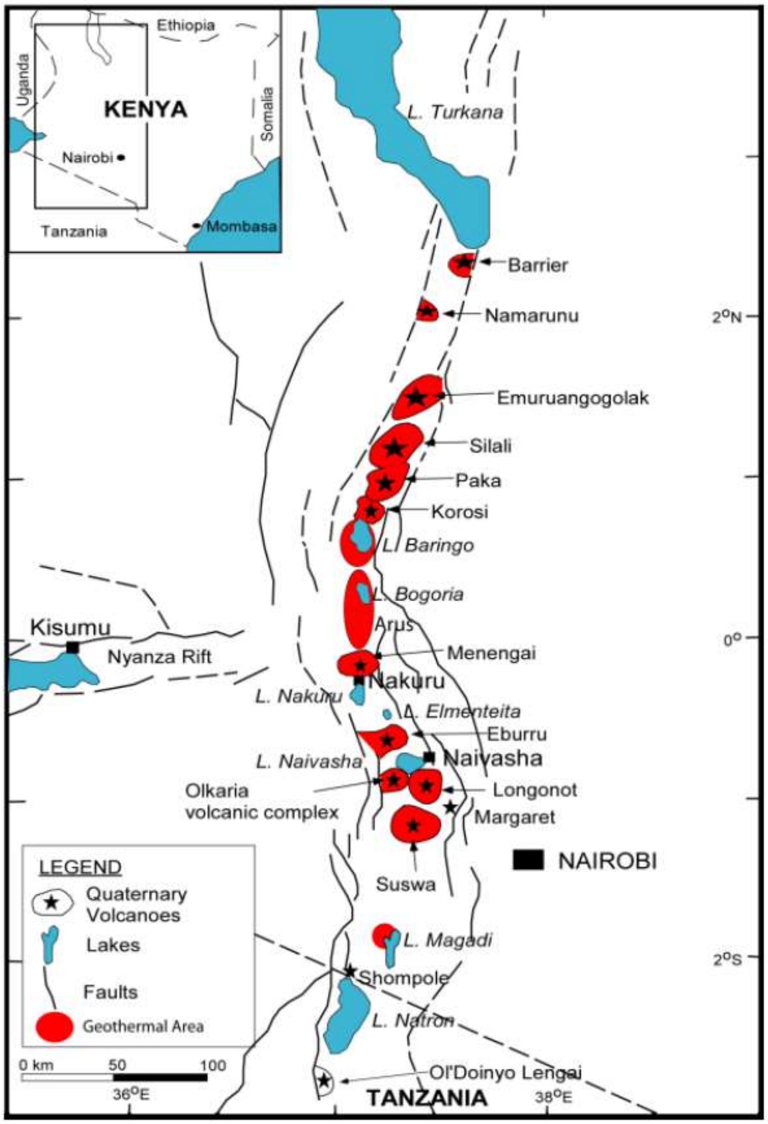
Geothermal power development is projected to increase by 328 MW between 2020 and 2022 with the commissioning of the following power plants: Olkaria PPP with 140 MW; Olkaria 1 Unit 6 with 83.3 MW; Menengai caldera with 3x35 (105) MW.

KenGen has continued to appraise and develop several sectors of the Greater Olkaria field. In addition to the Menengai field development, GDC has started exploration drilling in Paka prospect. GDC also plans to drill exploratory wells in Silali, Korosi and the Greater Menengai field within the next few years.

Having recognized the potential role that could be played by private investors, the Government of Kenya (GoK) has so far licensed 13 IPPs to undertake greenfield projects at Barrier, Longonot, Akiira, Elementaita, Homa Hills, Menengai North, Lake Magadi, Arus, Baringo, Emuruangogolak, Namarunu, and Emuruapoli prospects (Omenda et al., 2020). According to licensing conditions, the IPPs are required to drill exploration wells within three years of license issuance. The GoK is continuing with its ambitious plan to increase the geothermal installed capacity to 5,000 MW by year 2030.

The formation of the Kenya Rift began during the Pliocene (about 30 million years ago) with uplift and volcanism which became more intense about 14 million years ago. Subsequent to rifting was the development of the graben structure from about 5 million years ago, which was followed by fissure and central eruptions along the axis of the rift during 2 to 1 million years ago. Increased extension during the Quaternary period saw the development of large central volcanoes, most of which has an associated recognized geothermal area as shown in **Figure 57** (Omenda et al., 2020).

Figure 57. Location map of geothermal areas in Kenya (Source: Omenda et al., 2020)



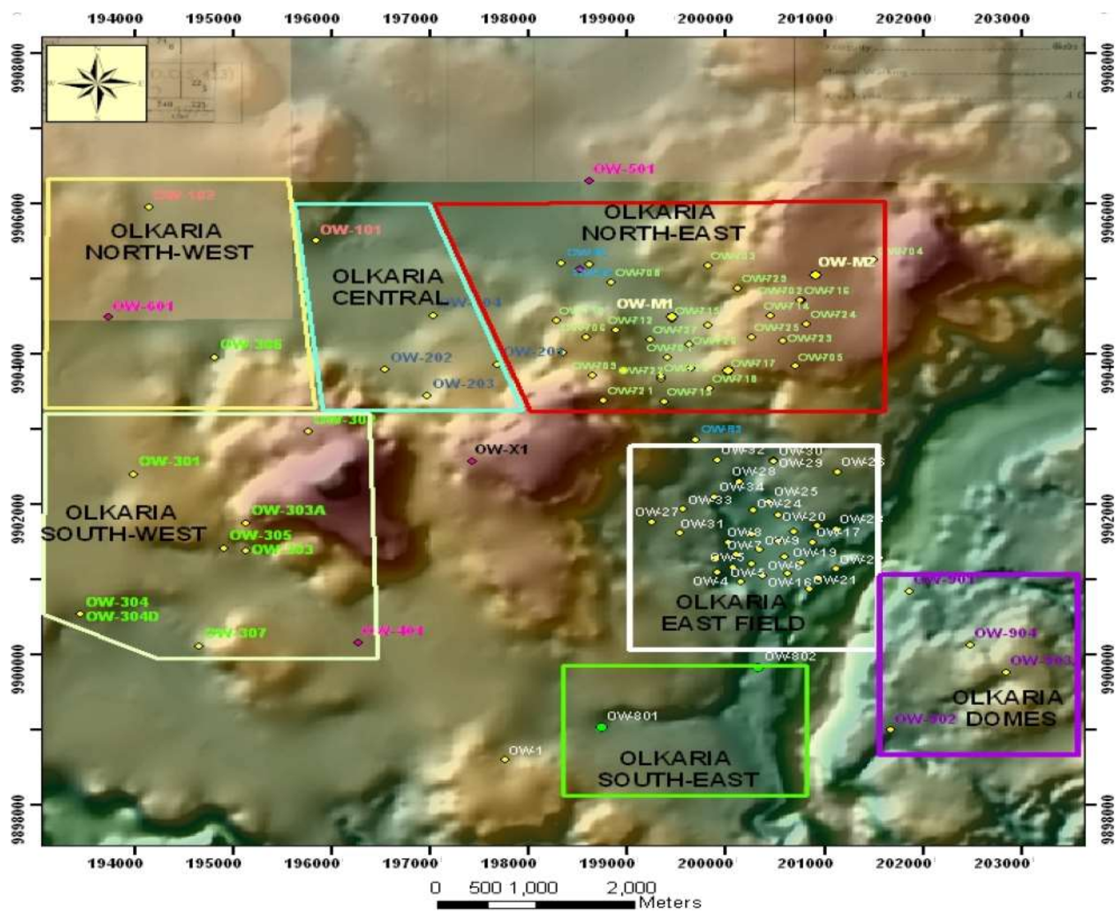
Greater Olkaria geothermal field. The first well (OW-1) was drilled in Olkaria in 1973 to the S of the present Olkaria East field, in an area which had strong fumaroles (Ouma, 2012). At 1,000 m the well encountered only 102°C: the area is now recognized to be the outflow of the Olkaria geothermal system. After a review of scientific results, the second well OW-2 was drilled in 1974 into the current Olkaria East field, followed by 5 appraisal wells from 1974 to 1976 which confirmed the existence of an exploitable geothermal resource.

Generation of electricity from geothermal resources in Olkaria began in June 1981 (Omenda et al., 2020), with the operation of the first power plant with an installed capacity of 15 MW. Five power plants have so far been constructed in the Olkaria geothermal field. They include: Olkaria I, II, III, IV and V.

The Greater Olkaria field is divided into seven sectors, in part corresponding to different fields, for the purpose of an easier management. The sectors include Olkaria East, Olkaria Domes, Olkaria South-East, Olkaria South-West, Olkaria North-West, Olkaria Central, and

Olkaria North-East (**Figure 58**). Currently (end of 2019), the total geothermal power installed capacity at Olkaria is 863 MW (see **Table 13**).

Figure 58. Geothermal sectors within the Greater Olkaria Geothermal Area (Source: Ouma, 2012)



Olkaria I power plant is the oldest geothermal plant in Kenya with 45 MW installed capacity. It has three units each generating 15 MW, tapping steam from the **Olkaria East field**. The first unit was installed in June 1981, the second unit in November 1982 and the third unit in March 1985 (**Table 13**). The three units utilize steam from 22 wells. One well is used for re-injection while 10 wells are used as standby wells. To fully utilize steam tapped after further exploration and drilling of the Olkaria East and North-East fields, a 150 MW Olkaria IAU plant (Units 4 and 5) was developed and commissioned in 2014. Furthermore, the construction of an 83.3 MW Olkaria IAU (Unit 6) power plant to use the excess steam in the two fields is underway.

Olkaria II power plant taps its steam from the **Olkaria North-East field** sector with a total capacity of 105 MW. The plant has three units, each generating 35 MW. The first two units were commissioned in 2003 while the third unit was commissioned in 2010. The plant utilizes steam from 22 wells. The plant is owned and operated by KenGen.

Olkaria III. After the power sector reforms of 1996, ORMAT international was licensed by the GoK to explore and generate power from the **Olkaria South-West field** in 1997. In 2000, ORMAT through its local subsidiary OrPower 4 Inc., commissioned an 8 MW combined cycle pilot plant called Olkaria III. This was later increased to 12 MW. In 2009, OrPower 4 further commissioned a 35 MW unit, followed by a 36 MW in 2013, 26 MW unit in 2014, 29.6 MW unit in 2016 and 15 MW in 2018, bringing the total to 155 MW. OrPower 4 uses the combined cycle plant technology to generate the 155 MW.

Olkaria IV. Detailed surface exploration resulted in the drilling of seven production wells in **Olkaria Domes** sector in 2007. With improved drilling technology allowing deeper and directional wells, the tapped geothermal resource was able to sustain more than 150 MW. This resulted in the start of the construction and commissioning of the 150 MW Olkaria IV power plant in October 2014. The plant has 2 units generating 75 MW each. The plant is owned and operated by KenGen. GDC supplies part of the steam requirements for the Olkaria IV and Olkaria IAU power plants.

Wellhead Generation. The wellhead technology has been developed to allow an early utilization of steam from production wells before they are connected to conventional power plants (Saitet and Kwambai, 2015). Unlike the main generating power plants, it takes relatively short time (6-12 months compared to the 24-36 months taken by main power plants) to put up and commission a wellhead generator, hence ensuring quick return on investment from geothermal resources. The first wellhead generator at Olkaria was commissioned by KenGen in June, 2012, in the Olkaria East field with a generation capacity of 5 MW. KenGen accelerated the installation of wellhead generators between 2014 and 2018 with installation of 15 wellhead generators having an aggregate capacity of 81.1 MW (Omenda et al., 2020).

Oserian Power Plant. Oserian Development Company Ltd owns and operates geothermal power plants for its own uses in greenhouses and farm installations located in the **North-West sector** (Omenda et al., 2020). The Company installed a 1.8 MW binary plant in 2004 using steam from well OW-306 that was drilled as an exploration well by KenGen, but was not used due to long distance to KenGen power plants. In 2006, the Company installed a second 1.8 MW backpressure power plant for its own use. This latter plant uses steam leased from KenGen.

Table 13. Power plants at Greater Olkaria, Eburru and Menengai fields as of December 31, 2019 (in operation, construction or planned) (Source: Omenda et al., 2020)

Locality	Power Plant Name	Year Commissioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe[3)]	Total Running Capacity MWe[4)]	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
Olkaria	Olkaria I Unit 1	1981	1	Operating	1F	15	15	124,830	
Olkaria	Olkaria I Unit 2	1982	1	Operating	1F	15	15	124,830	
Olkaria	Olkaria I Unit 3	1985	1	Operating	1F	15	15	124,830	
Olkaria	Olkaria II (Unit 1&2)	2003	2	Operating	1F	70	70	582,540	
Olkaria	Olkaria II Unit 3	2010	1	Operating	1F	35	35	291,270	
Eburru	Eburru	2010	1	Operating	B	2.52	2.52	20,971	
Oserian	Oserian	2004 and 2006	2	Operating	B, 1F	3.6	1.8	14,980	
Olkaria	Olkaria Wellhead	2013	1	Operating	1F	5	5	41,610	
Olkaria	Olkaria Wellheads	2014	4	Operating	1F	12.8	12.8	106,522	
Olkaria	OrPower 4 -Unit I	2000	4	Operating	B	52.8	52.8	439,402	
Olkaria	OrPower 4 -Unit II	2008	4	Operating	B	39.6	39.6	329,551	
Olkaria	OrPower 4 -Unit III	2014	1	Operating	B	17.6	17.6	146,467	
Olkaria	Olkaria IV Unit 1	2014	1	Operating	1F	75	75	624,150	
Olkaria	Olkaria IV Unit 2	2014	1	Operating	1F	75	75	624,150	
Olkaria	Olkaria I Unit 4	2014	1	Operating	1F	75	75	624,150	
Olkaria	Olkaria Wellheads	2014	6	Operating	1F	32.8	32.8	272,962	
Olkaria	Olkaria Wellheads	2014	5	Operating	1F	30.5	30.5	253,821	
Olkaria	Olkaria I Unit 5	2014	1	Operating	1F	75	75	624,150	
Olkaria	Orpower4	2015-2018		Operating	B	45	45	374,490	
Olkaria	Olkaria V	2019	2	Operating	1F	173.2	173.2	592,344	
Olkaria	Olkaria I Unit 6	2020	2	Construction	1F				83.3
Olkaria	Olkaria PPP	2022	2	Planned	1F				140
Menengai	Menengai	2021	3	Construction	1F				105
Total						865	864	6,338,019	328

1F = Single Flash	B = Binary (Rankine Cycle)

Eburru Geothemal Field. Eburru is a Quaternary volcano located to the N of Olkaria in an area of high physiography marked by the Eburru hills. Detailed surface studies were undertaken by KenGen in 1987-1990 which culminated in the drilling of 3 exploration wells in 1989-1991, confirming the existence of a geothermal system under the volcano. Subsequently 3 appraisal wells were drilled which indicated that the resource is small and is restricted to an area defined by a ring of explosion craters measuring 4 km in diameter. Out of the wells drilled, well EW-01 encountered over 250°C and is able to supply steam to a 2.5 MW well head generating unit operated by KenGen that was commissioned in 2012, while the others either flow low enthalpy fluids (EW-04, EW-06) or are non-productive (Omenda and Karingithi, 1993). However, MT/TEM surveys undertaken after well drilling allowed to refined the old conceptual model, suggesting the planning of an additional field development of about 25 MW. Surface studies have been extended also to the Badlands area N of Eburru volcano (Kubai and Kandie, 2014). Currently, plans are underway to drill new appraisal and production wells.

Menengai geothermal Field. Menengai is a large caldera volcano within the axis of the Kenya Rift Valley north of Nakuru town, about 160 km from Nairobi (Omenda et al., 2020). Initial exploration was undertaken by KenGen in 2004 and detailed surface studies were concluded by GDC in 2011, resulting in siting of exploration wells. Exploration drilling started in 2011 and currently 49 deep wells with depths varying from 2,100 m to 3,200 m have been drilled, with 25 of them tested. A number of wells have encountered temperatures higher than 400°C at 2,000 m making Menengai caldera the hottest geothermal system drilled in Africa. At least 6 wells may have been drilled into magma and had to be terminated before reaching the planned target. GDC is planning the project development in stages up to an estimated 465 MW.

The present development stage foresees the delivery by GDC of steam to 3 IPPs which are building 3 power plants with a capacity of 35 MW each, for a total of 105 MW. The 3 IPP are: Quantum East Africa Power Ltd.; OrPower 22 Ltd., (a consortium of Ormat, Civicon and Symbion); and Sosian Menengai Geothermal Power Ltd. (SMGPL) (Omenda et al., 2020). The 105 MW Menengai geothermal power plant is planned under the signed Project Implementation and Steam Supply Agreement (PISSA), which mandates GDC to provide steam and manage the reservoir during generation, while the IPPs to finance, design, construct, install, operate and maintain the plants on a Build-Own-Operate basis. KPLC (Kenya Power and Lighting Company), which is the off-taker, has signed a PPA agreement with the IPPs.

Paka prospect, located about 20 km N of Lake Baringo. Paka is a young Quaternary volcano located in the northern part of Kenya Rift Valley. The prospect, assigned to GDC, is dominated by a 7.5 km wide graben bound by eastern and the western normal faults. It is a relatively small shield volcano constructed largely by trachyte. Paka is one of the areas with the most active geothermal manifestations in the summit of the volcano that include fumaroles and sulphur deposits. Detailed surface studies revealed the existence of a geothermal system which has been confirmed by drilling undertaken by GDC in 2018-2019 (Omenda et al., 2020). Exploration wells being drilled were sited within the small caldera at the volcano summit and in the surrounding region of the volcanic edifice. GDC received a grant from the GRMF 3rd Application Round for the drilling of 2 full size wells to 2,500 m depth. The prospect potential is estimated at 450 MW.

The other geothermal prospects under active investigations (Omenda et al., 2020) are Barrier, Longonot, Suswa, Korosi, Silali, Homa Hills, Arus and Akiira (Figure 4/5.4).

Barrier prospect includes four overlapping shield volcanoes at the southern end on Lake Turkana, in northern Kenya. It was licensed to the Kenyan company Olsuswa Energy Ltd (http://www.olsuswaenergy.com), which undertook in 2019 detailed surface studies which revealed possible existence of a high temperature geothermal system within and surrounding the nested calderas of Kakorinya. Exploration drilling is planned for 2020.

Olsuswa Energy received a grant from the 3rd Application Round of GRMF for a detailed surface study including geological, geochemical and geophysical surveys in the Barrier prospect, with potential estimated at 500 MW.

Longonot volcanic complex is a Quaternary caldera volcano located in the southern part of the Kenya Rift, to the east of Olkaria (Alexander and Ussher, 2011). The prospect was licensed to Africa Geothermal International Ltd (http://www.africa-geothermal.com/) in 2009 and the concessionaire has undertaken detailed surface studies. Exploration drilling was initially planned for 2013, but because of several delays, the drilling phase was subsequently rescheduled for 2019-2020. Africa Geothermal International received a grant from the 1st Application Round of GRMF for the drilling of 2 full size wells to 2,500 m depth in the Longonot prospect, with potential estimated at 140 MW.

Suswa is a Quaternary caldera volcano located in the southern part of the Kenya Rift Valley. The prospect includes a central volcano with an outer and inner caldera. Suswa was initially licensed to a private developer, but the license reverted to the government who then assigned GDC to develop the prospect. New detailed studies including fumarole sampling, a CO_2 flux survey, geology and structures mapping, MT-TEM resistivity surveys and a gravity survey, have been undertaken in 2016 by GDC with the support of ICEIDA and NDF (Haizlip et al., 2020). The conceptual model derived from the integrated analysis of available data includes a magmatically-heated, 250-300ºC, neutral, low-gas, partially two-phase reservoir associated with hot volcanic rocks overlying recent intrusions that may include magma at 2.5 to 5 km depth within the Suswa inner caldera. Partial funding has been obtained by GDC for exploration drilling and infrastructure development.

Korosi prospect, located immediately north of lake Baringo, and **Silali** prospect, a large caldera volcano located about 50 km north of Lake Baringo, were evaluated in detail by GDC in 2016, showing the potential existence of high temperature geothermal systems. The studies were supported by technical assistance from JICA and UNEP. GDC plans to drill exploration wells in the prospects as part of the ongoing drilling works in the so called **Baringo-Silali** geothermal block which also includes the Korosi and Paka prospects (Lichoro, 2020). The whole development of the block is planned in 3 phases of 100 MW each (https://www.thinkgeoenergy.com/first-well-successfully-drilled-for-baringo-silali-geothermal-project-in-kenya/). GDC received a grant from the 1st Application Round of GRMF for the drilling of 2 full size wells to 2,500 m depth in the Silali prospect, with potential estimated at 800 MW. GDC received also a grant from the 3rd Application Round of GRMF for the drilling of 2 full size wells to 2,500 m depth in the Korosi prospect, with potential estimated at 450 MW.

Homa Hills prospect, located in the Nyanza Rift on the shores of Lake Victoria, has been licensed to Capital Power Ltd (http://capitalpower.co.ke/). Capital Power received a grant from the 4th Application Round of GRMF for a detailed surface study including geological survey, soil gas survey, MT, gravimetric and magnetic surveys in the Homa Hills prospect, with potential estimated at 45 MW. Preliminary studies undertaken in the area indicate that the geothermal reservoir is at temperatures of over 165°C and covers an area of some 12 km^2.

Arus prospect, located to some 15 km WSW of lake Bogoria, has been licensed to Arus Energy Ltd (http://arusenergy.com/). Arus Energy Ltd. received a grant from the 4th Application Round of GRMF for a detailed surface study including thermal gradient wells, geological, geochemical and geophysical surveys in the Arus prospect, with potential estimated at 80 MW and reservoir temperature higher than 230°C.

Akiira prospect, located to the SE of Olkaria, has been licensed to Akiira Geothermal Ltd (http://www.akiiraone.com/). Two exploration wells were drilled by KenGen as drilling contractor with non-satisfactory results. A new surface exploration study has been awarded to KenGen in early 2020 in order to set the basis for additional exploratory drilling (https://www.thinkgeoenergy.com/akiira-geothermal-project-in-kenya-hires-kengen-for-geoscience-study/). Akiira Geothermal received a grant from the 2nd Application Round of GRMF for the drilling of 2 full size wells to 3,000 m depth in the Akiira prospect, with potential estimated at 140 MW.

Other prospects that include Lake Baringo, Elementaita, Namarunu, Emuruangogolak, and Lake Magadi, licensed to GDC and private developers, are still in the planning stages (Omenda et al., 2020). The geothermal sites listed in the AGID data base are shown in **Table 14**.

Table 14. AGID -Kenya Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/kenya.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
Olkaria	Kenya	1000		Yes	Yes	Yes
Eburru	Kenya	60		Yes	Yes	Yes
Longonot	Kenya	700		Yes	Yes	No
Menengai	Kenya	1000		Yes	Yes	Yes
Arus-Bogoria	Kenya	100		Yes	Yes	No
Silali	Kenya	1000		Yes	Yes	No
Emuruangogolak	Kenya	500		Yes	No	No
Paka	Kenya	200		Yes	Yes	No
Barrier	Kenya	500		Yes	No	No
Chyullu Hills	Kenya			Yes	No	No
Namarunu	Kenya			No	No	No
Korosi-Chepchuk	Kenya	550		Yes	Yes	No
Baringo	Kenya	100		Yes	Yes	No
Bogoria	Kenya			No	Yes	No
Badlands	Kenya			No	Yes	No
Suswa	Kenya			Yes	Yes	No
Magadi	Kenya			Yes	No	No
Homa hills	Kenya			Yes	Yes	No
Mwananyamala	Kenya			Yes	Yes	No

Table 15 shows the main Kenyan national organizations listed in the AGID data base. Kenya Power and Lighting Company (KPLC) (https://kplc.co.ke/) is a state-controlled utility which since 1997 is in charge of transmission and distribution of electricity only. KPLCs key mandate is to plan for sufficient electricity generation and transmission capacity to meet demand, building and maintaining the power distribution and transmission network and retailing of electricity to its customers.

Kenya Electricity Generating Company (KenGen, https://www.kengen.co.ke/, formerly Kenya Electricity Generating Company) was incorporated in 1998 with the mandate to undertake grid electricity generation functions now accomplished with the operation of Hydro, geothermal, thermal, Solar and Wind power plants. In particular KenGen inherited the geothermal activities previously managed by KPLC, including Olkaria and Eburru geothermal fields. Within the Greater Olkaria field, KenGen drilled over 300 wells using both international drilling contractors (mainly Chinese) as well as its own drilling rigs operated by KenGen personnel. In addition to the use of its own drilling rigs and crews, KenGen is capable to provide with its personnel all related specialized services including mud engineering, cementing engineering, aerated drilling, directional drilling, geological site assistance, well logging and testing.

Kenya Electricity Transmission Company (KETRACO) (https://ketraco.co.ke/) was incorporated in 2008 to take up the transmission function from KPLC, while Geothermal Development Company (GDC) (http://www.gdc.co.ke/) was incorporated always in 2008 to undertake the riskier upstream stages of geothermal exploration and development. Part of GDC roles are therefore to undertake surface exploration of geothermal fields, undertake exploratory, appraisal and production drilling, develop and manage proven steam fields and enter into steam sales or joint development agreements with investors in the geothermal sector (Omenda et al., 2020).

In order to accomplish its mandate, GDC purchased a total of 7 electrical driven (2,000 HP) drilling rigs with a nominal capacity of 5,000 m depth with 5" drill pipes. GDC is using its own drilling crews and engineers to operate the rigs. GDC performs with its own personnel and equipment the cementing services, the air drilling services, the geologic site assistance, as well as well logging and testing operations. This allows GDC to drill geothermal wells at a competitive price with respect to foreign drilling contractors. On the other hand, the management of the drilling rigs fleet with all related services and consumable material procurement, proved to be challenging for GDC, resulting at the beginning of drilling operations in Menengai in a consistent fraction of lost time related to stand-by and fishing operations. In order to improve GDC performance in geothermal exploration and drilling, from 2013 to 2019, JICA and GDC collaborated on a technical cooperation project for Capacity Strengthening for Geothermal Development in Kenya (Wakamatsu et al., 2020). The project aimed to improve GDC's capacity to manage various technical risks through both formal and on-the-job training of GDC staff in Menengai.

EPRA (Energy & Petroleum Regulatory Commission, formerly ERC) (https://www.epra.go.ke/) is the authority in charge of regulation, monitoring and supervision of the activities related to generation and transmission of electric energy, and production and commercialization of petroleum products and coal. The energy sector in Kenya is managed by the Ministry of Energy & Petroleum (MoEP, https://www.kpc.co.ke/moep/), which generates policies that are designed to create an enabling environment for efficient operation and growth of the sector. It sets the strategic direction for the growth of the sector and provides a long-term vision for all involved players.

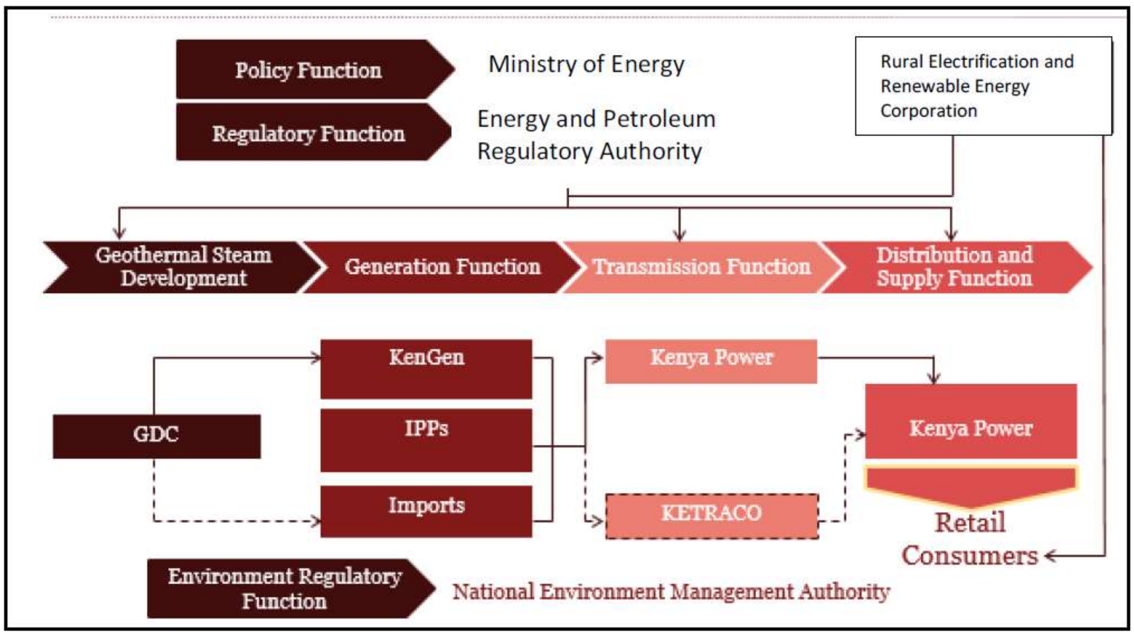
Table 15. AGID -Kenya Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/Kenya.php)

Organization	Country	Name	Status
ERC	Kenya	Energy Regulatory Commission	Active
GDC	Kenya	Geothermal Development Company	Active
KenGen	Kenya	Kenya Electricity Generating Company, Ltd.	Active
KETRACO	Kenya	Kenya Electricity Transmission Co. Ltd.	Active
KPLC	Kenya	Kenya Power and Lightning Company	Active
MoEP-Kenya	Kenya	Ministry of Energy and Petroleum	Active

The institutional setup on Kenya energy sector, with specific reference to the geothermal energy sector, is summarized in **Figure 59** (Omenda et al., 2020). The geothermal steam development is mainly devoted to GDC which shall deliver the produced steam to KenGen (as in Olkaria) or to IPPs, as is the case of the Menengai caldera field development. Actually, licenses for field exploration and development have been already assigned to private operators, such as Olsuswa Energy Ltd, Africa Geothermal International Ltd, Capital Power Ltd, Arus Energy Ltd and Akiira Geothermal Ltd.

In the developed Kenyan geothermal energy sector Public Private Partnerships (PPP) models have become increasingly important drivers of promoting renewable energy growth over the last decade with GoK facing increasingly constraint budgets (Kiptanui and Kipyiego, 2020). These PPP models are now gaining traction in Kenya's geothermal resource development with geothermal projects of over 2,000 MW already approved for implementation and with 245 MW at advanced stages of implementation by GDC and KenGen, which intend to sell the steam under PPP steam supply contracts, a separate business from steam conversion to electricity.

Figure 59. Kenya Energy sector Institutional setup, with specific reference to the geothermal sector (Source: Omenda et al., 2020)



The PPP Act No.15 of 2013 recognizes various schemes, listed in **Table 16** in order of generally increasing involvement and assumption of risks by the private sector. Ten geothermal power projects with a cumulative capacity of 2,455 MW have been approved under the PPP arrangement Act and are at various stages of development as shown in Table 5/5.4

Kenya is therefore the leading country in Africa as far as the development and exploitation of geothermal resources is concerned. The development of the Greater Olkaria Field is a success story witnessing the capabilities acquired by KenGen in all the different phases of resource development, from surface exploration and deep drilling to plant construction and field exploitation. Such capabilities are now used by KenGen to provide technical services to other operators inside and outside Kenya such as exploration surveys performed in Bayuda (Sudan), Karisimbi (Rwanda), Kapisya and Chinyunyu (Zambia), and those performed in Comoros, Uganda, and Djibouti, and drilling operations conducted at Akiira field (Kenya) and Tulu Moye field (Ethiopia).

GDC also developed in over 10 years of activity strong experiences and capabilities in surface exploration and well drilling, in particular at the Menengai caldera field, with on-going and future drilling projects at Paka, Suswa, Korosi and Silali. GDC too is providing exploration services outside Kenya in other East Africa countries and is starting to bid for geothermal drilling projects outside Kenya, such as in Ethiopia.

Table 16. PPP Schemes in Kenya. Source: Public Private Partnership Act No.15 of 2013 (Source: Kiptanui and Kipyiego, 2020)

PPP Arrangement	Main Variants	Ownership of Capital Assets	Responsibility of Investment	Assumption of risk	Contract Duration
▪ Management contract	Management and performance	Public	Private	Private	≤ 10 Yrs
▪ Output Performance	operation, maintenance and management	Public	Private	Private	≤ 10 Yrs
▪ Lease	Lease, manages, operates and maintains and pays rent or royalties	contracting authority	Private	Private	≤ 30 Yrs
▪ Concession	operate, maintain, rehabilitate or upgrade an infrastructure facility-charge a user fee while paying a concession fee	contracting authority	Private	Private	≤ 30 Yrs
▪ Build-Own-Operate-Transfer	designs, constructs, finances, operates and maintains	Public/Private	Public/Private	Public/Private	≤ 30 Yrs
▪ Build-Own Operate	designs, finances, constructs, operates and maintains	Private	Private	Private	≤ 30 Yrs
▪ Build-Operate-and-Transfer	finances, constructs, operates and maintains and transfers	Public/Private	Public/Private	Public/Private	≤ 30 Yrs
▪ Build-Lease-and-Transfer	finance and construct, develop, lease & transfers	Public	Public	Public/Private	≤ 30 Yrs
▪ Build-Transfer-and-Operate	Constructs, transfers & operate	Public/Private	Public/Private	Public/Private	≤ 30 Yrs
▪ Develop-Operate-and-Transfer	Develop, transfers	Public/Private	Public/Private	Public/Private	≤ 30 Yrs
▪ Rehabilitate-Operate-and-Transfer	Refurbishes, operates and maintains	Public/Private	Public/Private	Public/Private	≤ 30 Yrs
▪ Rehabilitate-Own-and-Operate	Transfer, refurbish & operate	Public/Private	Public/Private	Public/Private	≤ 30 Yrs
▪ Land Swap	Transfers existing public land or asset				

The geothermal market in Kenya is the most developed, with a clear institutional set-up allowing the active participation of both public and private operators with provisions for public-private collaborations with different Public Private Partnerships (PPP) models. Concessions have been assigned to several Kenyan and international operators with already planned developments in the order of more than 2,000 MW to be installed.

The Kenyan success story is for sure an example for all the other East Africa countries willing to utilize their geothermal resources.

Table 17. PPP approved geothermal projects (Source: PPP Unit website) (Source: Kiptanui and Kipyiego, 2020)

No	Project	Contracting Authority	Project Cost (M$)	PPP Model & Duration	Status
1.	50MWe Olkaria Wellheads Geothermal Projects	KenGen	-	Built, lease, operate & maintain	operational
2.	35MWe Sosian Menengai Geothermal Power Plant Project	GDC	79.15	BOO (25 yrs.)	Commercial/ financial close
3.	35MWe Quantum Menengai Geothermal Power Plant Project		79.15	BOO (25 yrs.)	Commercial/financial close
4.	35MWe Orpower Geothermal Power Plant Project		82.00	BOO (25 yrs.)	Commercial/financial close
5.	140MWe Olkaria Geothermal PPP project - Phase 1	KenGen	2,000	BOOT (25 yrs.)	Procurement
6.	420MWe Olkaria Geothermal PPP project - Phase 2			TBD	Proposal stage
7.	280MWe Olkaria VII & VIII		-	TBD	Drilling stage
8.	360MWe Menengai Phase 2	GDC	-	TBD	Drilling stage
9.	800MWe Baringo-Silali Phase 1		-	TBD	Drilling stage
10.	300MWe Suswa Geothermal Plant		-	TBD	Preliminary stages

BOO - Build-Own-Operate, BOOT - Build-Own-Operate-Transfer, BLOM – Built-Lease-Operate-Maintain, TBD: To be determined

3.5 Tanzania

Tanzania (The United Republic of Tanzania) is located at the south end of the Eastern Branch of EARS, where it joins the Western Branch (**Figure 60**). Tanzania experienced a population growth from 7.6 M in 1950, to 33.5 M and 58.0 M in 2000 and 2019, respectively. The GDP rose from 13.4 B USD in 2000 to 32 and 59 B USD in 2010 and 2019. About 66% of the people still live in rural areas mainly employed in subsistence agriculture. The access rate to electricity increased from 9.6% in 2000 to 16.4% in 2013 and experienced a sharp increment to 32.8% in 2017. (https://www.macrotrends.net/countries/TZA/tanzania/electricity-access-statistics).

The TPES by source of generation shown in **Figure 61** shows a strong increment of energy generation by Biofuels (wood and charcoal) which is related to the population strong increment with most of the people still living in rural areas. There is also a substantial increment of Oil consumption and, from about 2005, the use of natural gas. As far as the electricity generation by source shown in **Figure 62** is concerned, in 2017 Hydro generation represented an important fraction of about 30% while the remaining was supplied by Oil (about 18%, all imported) and mostly by natural gas (about 52%, produced from national gas reserves). Hydro generation is subject to strong variations depending on drought periods, which are compensated since year 2005 by generation with Oil and Natural gas. (https://energypedia.info/wiki/Tanzania_Energy_Situation#Introduction). The annual electricity consumption per capita, at 84 kWh/capita in 2008, is currently about 133 kWh/capita, but the Government of Tanzania (GoT) vision is to increase by 2025 the annual electricity consumption to 490kWh/capita.

Figure 60. Map of Tanzania (Source: https://www.britannica.com/place/Tanzania)

As of May 2019 (Kajugus et al., 2020), the total installed generation capacity for the grid system was 1,601.9 MW; grid installed capacity was 1565.7 MW and off-grid was 36.2 MW. Hydropower accounted for 573.7 MW (36.6%), natural gas power plants contributed with 892.7 MW (57.2%) and liquid fuel power plants was 88.8 MW (5.7%), and biomass was 10.5 MW (0.6%).

According to the Power System Master Plan (2016 update), the electricity demand is growing between 10% and 15% per annum and is forecasted to increase more due to growing energy requirements in transport, mining and industry sectors. Currently, there is no contribution from geothermal generation, however, geothermal energy is expected to contribute, as a short-term target, 200 MW to the ambitious national grid electricity target of 10,000 MW by 2025. Thus, geothermal energy is expected to give a quite small contribution to the electric generation grid of the country.

Figure 61. Total primary energy supply (TPES) by source in Tanzania, period 1990-2017 (Source: https://www.iea.org/data-and-statistics)

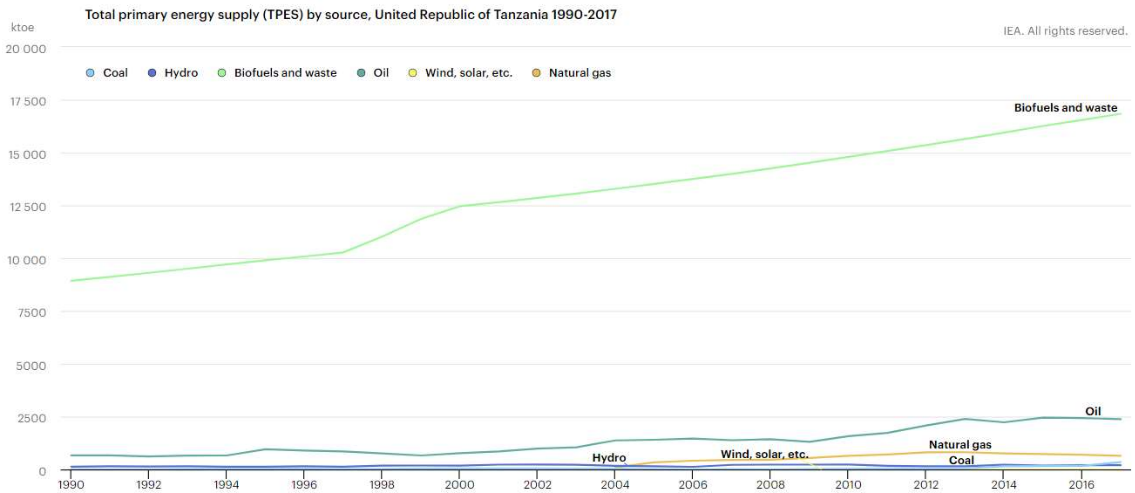
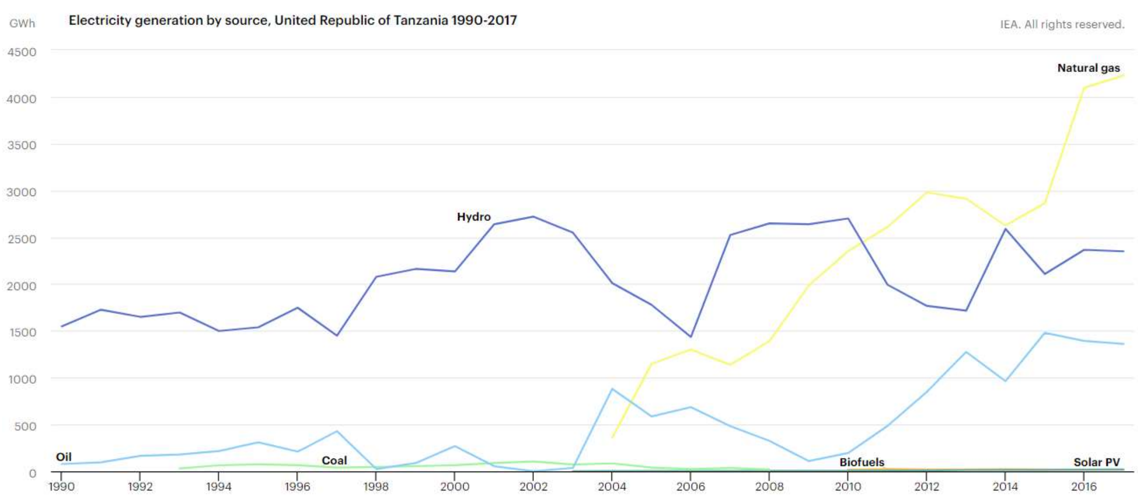


Figure 62. Electricity generation by source in Tanzania, period 1990-2017 (Source: https://www.iea.org/data-and-statistics)



Tanzania is interested by both the Eastern and Western Branches of the EARS which converge in SW Tanzania, in principle holding a significant geothermal potential which has been estimated, from surface exploration data only, up to 5,000 MW by Kajugus et al. (2020) and, more realistically, at 500 MW by Omenda (2018b). Most of geothermal prospects have distinct surface manifestations, mainly hot springs. Geothermal exploration started in 1976 with a country assessment performed by SWECO and VIRKIR (SWECO, 1978) followed by another supported by TANESCO performed in 1995 by GST in collaboration with the Un. Of Auckland, New Zealand. To date, over 50 clusters of hot springs have been identified in the country occurring in diverse geological settings, which are divided into four zones as shown in **Figure 63** (Kajugus et al., 2020). The main geological features of the four zones are as follows:

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

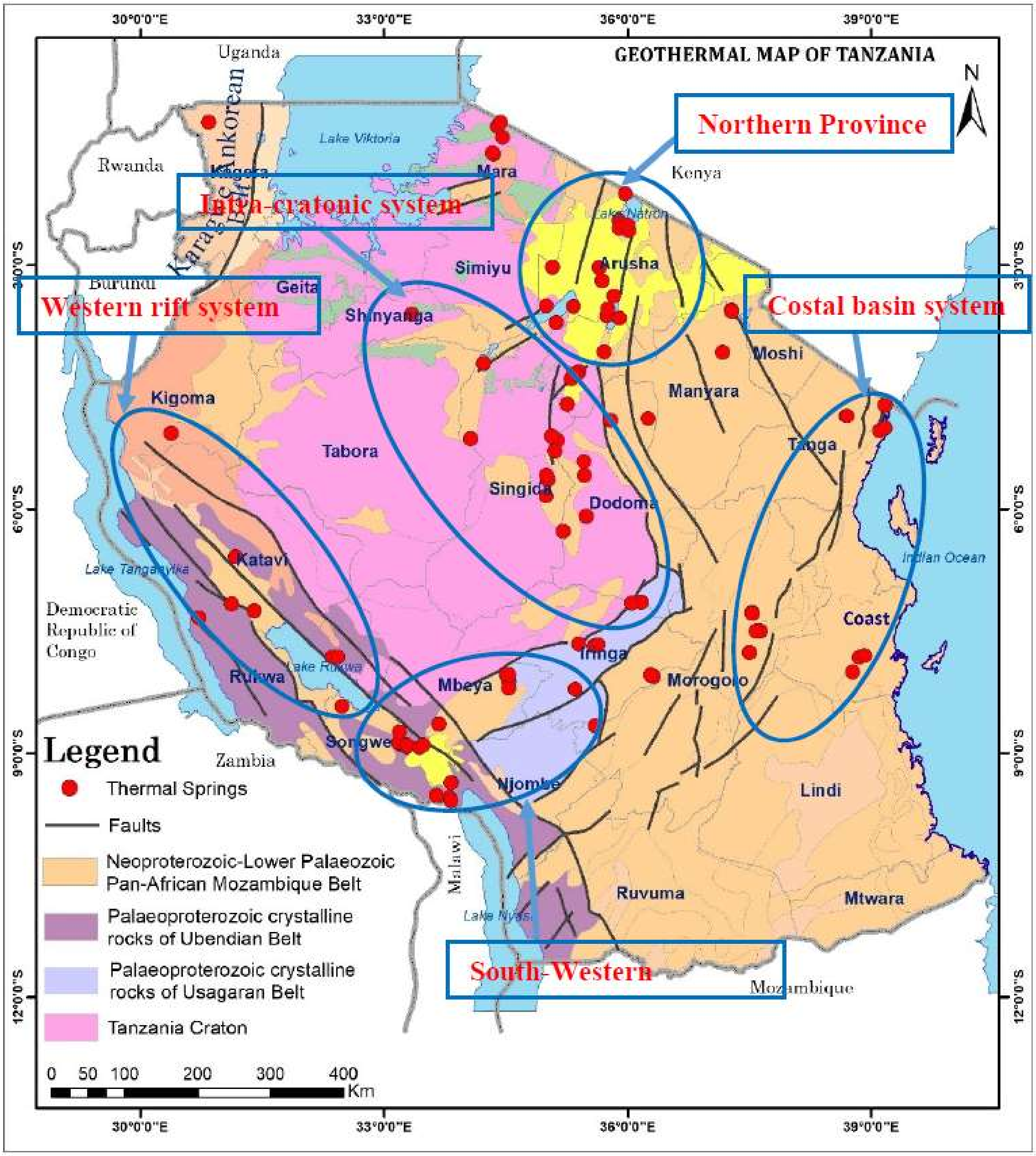
(ii) Coastal basin geothermal systems: includes geothermal resources in Morogoro, Costal and Tanga regions. The occurrence is associate with coastal sedimentary basins, mainly fault hosted systems. Some of the geothermal prospects occurring in the coastal basins includes Kisaki, Tagalala, Mtende, **Luhoi**,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

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

(iv) Western rift geothermal systems: occurring in the Western Branch of the EARS which is seismically active. Prospects include Mtagata, Maji, Rukwa, Mapu, Ivuna and Rock of Hades.

The GoT has set up short and long-term targets that has to be attained in 5 and 25 years respectively. The short-term target, entrusted to TGDC, is to add 200 MW from geothermal resources to the national grid by 2025. In order to accomplish the above target, TGDC is implementing 4 flagship projects, namely: Ngozi, Songwe, Kiejo-Mbaka and Luhoi (Kajugus et al., 2020). In addition to the flagship projects, the GoT has prioritized three main strategic focus areas to ensure sustained geothermal development: (i) establishing a suitable business environment for geothermal development through formulation of legal and regulatory framework, (ii) strengthening local technical capability and (iii) improving research and development of the geothermal sector.

Figure 63. Simplified geological map of Tanzania with geothermal regions and location of major thermal springs (Source: Kajungus et al., 2020)



The 4 flagship projects have reached a resource confirmation stage through test drilling which is planned to be executed in coming years. Results of the surface exploration studies, development strategies and current status of each project are summarised here below.

Ngozi Geothermal Prospect. The Ngozi geothermal prospect is located within the Rungwe Volcanic Province, SW Tanzania, at rift intersection of the Western and Eastern Branches of the EARS (Kajugus et al., 2020). It has been explored (geologically, geophysical and geochemically) since 1950's, with recent comprehensive surface surveys performed by the Geothermal Service of Tanzania (GST), TANESCO and BGR within Phase I (2006-09) and Phase II (2009-23) of GEOTHERM program (MEM et al., 2013).

TGDC, with technical assistance from UNEP-ARGeo and MFA/ICEIDA and support by GDC, has carried additional surface surveys in the area with the intention of updating the conceptual model of the geothermal system and of selecting drilling targets to confirm the resource characteristics and potential. The study concluded in 2016, supported by the advisory services of 3 international consultants, suggested that an inferred liquid dominated geothermal reservoir is located beneath Ngozi crater, with an estimated temperature of about 230°C, TDS in the order of 15,800 ppm, and CO_2 partial pressure of about 15 bar (Alexander et al., 2016a; 2016b).

The study further identified 5 locations for test drilling around Ngozi crater. TGDC was planning to drill 3 slim wells at 1,200-1,500 m depth within a project co-financed by the GRMF (4^{th} Application Round) which was started at the end of 2018. The project foreseen the preparation of technical specifications for the procurement of two drilling rigs, the design and construction of drilling infrastructures, as well as the design, drilling and testing of 3 slim holes and the completion of a pre-feasibility study. The drilling project was halted in the first half of 2019, after the completion of the planning and technical specifications phase, because of contractual problems with the supervision firm. TGDC has issued an invitation to tender for the supply of a small drilling rig with accessories on Feb. 27, 2020. No additional public info has been found about the actual status of drilling activities at Ngozi prospect.

Kiejo-Mbaka Geothermal Prospect. Kiejo-Mbaka geothermal prospect is located in the Southern part of the Rungwe Volcanic Province which host Ngozi, Rungwe and Kiejo volcanoes in the south west of Tanzania (Kajugus et al., 2020). Different studies have been undertaken in the prospect area. The most recent one is that performed by ELC-Electroconsult (2017a) which concluded that Kiejo-Mbaka is a medium temperature geothermal system with estimated reservoir temperature around 140°C. Surface manifestations are represented by hot springs in Kilambo, Kajala and Ilwalilo, with temperature in the range 59 – 64°C, recharged by meteoric water as confirmed by the isotopic studies.

The study by ELC-Electroconsult (2017a) has recommend resource confirmation by drilling exploration wells with 7 possible locations suggested. TGDC is planning to start with 4 wells, 3 of them being slim holes and one a full size well. The drilling programme is planned in the fiscal year 2020/21. Funds mobilization from different sources for carrying out of exploration drilling is underway. GRMF grant support under the 5^{th} Application Round has been awarded to the project which will be co-financed by the GoT.

Songwe Geothermal Prospect. Songwe prospect is located in Songwe Region, just North West of Ngozi prospect (Kajugus et al., 2020). Detailed surface study for this prospect was completed in 2016 by UNEP/ARGeo technical consultants being carried out together with Ngozi prospect (Alexander et al., 2016a; 2016b). The study shows that Songwe is a low to medium temperature resource (about 110ºC), suitable for direct use applications and possibly for power generation using ORC plants. The study further recommended to undertake a gap filling study to determine the appropriate drilling site locations and the number of wells prior to embarking on exploratory well drilling.

TGDC in collaboration with the Geothermal Facility (EAGER) carried out additional gap filling study in the area between October, 2017 and June 2018 (Heat et al., 2018; EAGER, 2018; Hinz et al., 2018), which allowed to conclude that Songwe occupies a pull-apart along a strike-slip fault system in the Songwe basin. The study recommended a Temperature Gradient Holes (TGH) drilling programme comprising 14 drilling locations to increase the knowledge about the system before undertaking exploratory drillings for resource confirmation and suitability for direct use applications and/or power generation. Considering the low expected temperature, a pre-feasibility study for direct uses applications prospect was also conducted at Songwe prospect by TGDC in collaboration with EAGER. The study proposed a number of multi direct utilization mini projects such as aquaculture, drying agricultural crops, and recreational (tourism). TGDC concluded that introducing agri-processing technology and developing tourism can have significant economic effect and benefits not only to the local community but also to the regional economy.

Luhoi Geothermal Prospect. Luhoi geothermal prospect is located within the Coast Region, about 150 km from Dar es Salaam (Kajugus et al., 2020). It is situated along the southern extension of the EARS. The prospect is characterised by several hot springs, at about 72°C and with 20-30 L/s flow rate, along the Luhoi River over a stretch of about 600 m and large amounts of accumulated travertine. A detailed surface study was conducted by ELC-Electroconsult (2017a) jointly with the Kiejo-Mbaka project under technical support from the MFA Iceland/ICEIDA. The results indicate that Luhoi geothermal prospect hosts a medium temperature geothermal system (95-145°C) and is suitable for direct uses and/or power generation using ORC plants.

Natron Geothermal prospect. TGDC has been awarded a grant from the 5th Application round of GRMF for surface studies in the Natron prospect located in the Northern province.

The AGID data base lists 3 geothermal sites (**Table 18**), among which the Ngozi and Songwe flagship prospect are included. On the third listed site, Kisaki – Morogoro, only reconnaissance surveys have been performed.

Table 18. AGID -Tanzania Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/tanzania.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
Ngozi-Mbeya	Tanzania			Yes	Yes	No
Songwe-Mbeya	Tanzania			Yes	Yes	No
Kisaki - Morogoro	Tanzania			Yes	No	No

The key players in the Tanzanian electricity and renewable energy sub-sector include the Ministry of Energy (MoE) responsible for the energy sector policies, the Tanzania Electric Supply Company Limited (TANESCO, http://www.tanesco.co.tz/) the national power utility in charge of generation, transmission and distribution of electric energy, the Rural Energy Agency (REA, http://rea.go.tz/Home/tabid/96/Default.aspx) in charge of the promotion of improved access to modern energy services in the rural areas, the Energy and Water Utilities Regulatory Agency (EWURA, https://www.ewura.go.tz/), and the Tanzania Geothermal Development Company Limited (TGDC, https://www.tgdc.go.tz/) in charge of geothermal energy development (Kajugus et al., 2020).

Tanzania has invested considerably on the national geothermal resources with the creation in 2011 of TGDC, a state-owned company with the main mission to develop the national geothermal sector. Several studies, from reconnaissance to detailed surface surveys have been already performed on 4 prospects considered by TGDC as flagship projects for a short-term target of 200 MW installed electric potential by 2025. Actually, 3 of the prospects, namely Kiejo-Mbaka, Songwe and Luhoi, are inferred to host geothermal reservoirs with low to medium temperatures for which a limited potential can be reasonably exploited using ORC plants. The most promising prospect, Ngozi, hosted in a volcanic environment with predicted reservoir temperatures in the order of 230°C, is still at the stage of exploratory drilling and testing due to the stop in 2019 of the exploratory drilling project started at the end of 2018. All that considered, it seems reasonable to conclude that the fulfilment of the short-term target of 200 MW to be installed before 2025 will be hardly accomplished. It is likely that more time will be needed for the exploration and field development and the construction of power plant and surface facilities. It is also reasonable to expect that a staged development will be chosen, making the early installation of all the planned 200 MW unlikely.

3.6 Comoros

Comoros (Union of the Comoros) is a small archipelago of 3 volcanic islands (Grande Comore, Mohéli, Anjouan) located between Mozambique and Madagascar in the Indian Ocean (

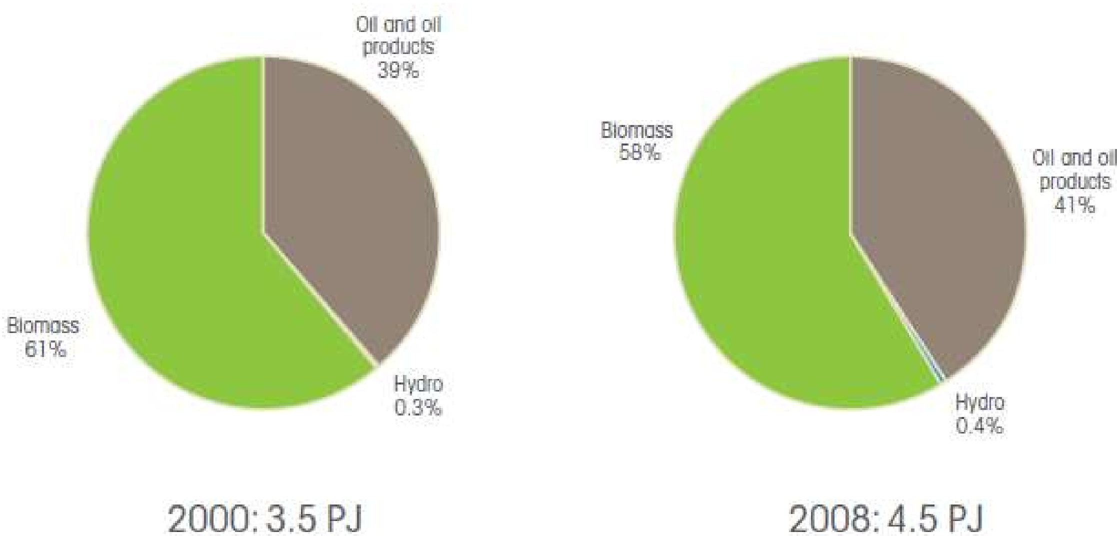
Figure 64). The 4th island of the archipelago, Mayotte, is administered by France. Comoros experienced a population growth from 159,500 in 1950, to 542,400 and 850,890 in 2000 and 2019, respectively. The GDP had an improvement, with a high variable trend, from 0.35 B USD in 2000 to 0.91 B USD and 1.20 B USD in 2010 and 2019, respectively. More than two third of the people live in rural areas employed in subsistence agriculture. The official access rate to electricity was stated at about 46% in 2010, but because of very frequent breakdowns, the actual electricity access rate was estimated to be around 30% (AfDB, 2016), but it was then reported close to 80% in 2017.

TPES by source of generation in 2000 and 2008 shown in **Figure 65** was dominated by Biomass and Oil, which is totally imported. The electricity consumption is extremely low, amounting to 84 kWh/capita in 2014. Total installed electric power was about 6 MW in 2010, of which 1 MW from renewables (IRENA, 2010), and about 22 MW in 2017, with a peak load of 14-15 MW (Houmadi et al., 2017). About 16 MW are installed in Grande Comore, with only 9 MW available. According to Chaheire et al. (2016), only 12 MW were actually available in 2016 mainly due to the fact that the company of Water and Electricity (at the time the Comoros public company in charge of electric production) generated electricity at a cost higher than the selling price.

It is clear that the development of an indigenous energy resource such as geothermal energy would have clear benefits for the electric supply in the Comoros which is now depending on expensive imported fuel oil. A 10 MW geothermal power plant in Grande Comore would already be enough to supply the base load for the present average electric energy consumption. Thus, Development of geothermal energy in the Comoros remains among the priority programs of the Government of the Union of Comoros.

Figure 64. Map of Comoros (Source: https://www.britannica.com/place/Comoros)

Figure 65. Total Primary Energy Supply (TPES) by source for Comoros in 2000 and 2008 (excluding electricity trade) (Source: IRENA, 2010)



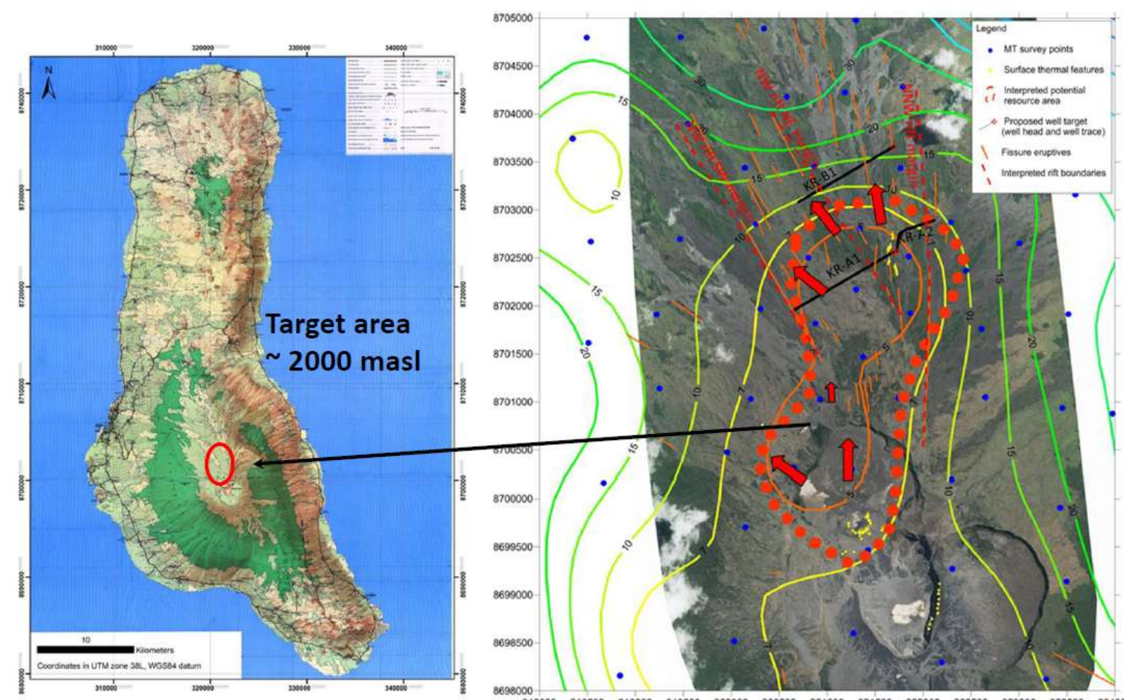
Three geothermal sites have been identified on Grande Mayotte island as listed in **Table 19**: La Grotte, La Grille and the Karthala volcano, the latter being the most promising one. First field works were done by KenGen (2008) who performed 5 MT measurements at the island scale and performed a geochemical survey with sampling of 5 water samples and one gas sample. The survey suggested the possible existence of a geothermal reservoir on the north flank of Karthala volcano with temperatures in the 250-300°C range.

Table 19. AGID -Comoros Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/comoros.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
KARTHALA	Comoros			Yes	No	No
la Grille	Comoros			Yes	Yes	No
La Grotte	Comoros			Yes	Yes	No

The Karthala volcano is a basaltic shield volcano with an active hydrothermal system on its flanks (**Figure 66**). It has multiple nested calderas at the top and heartbreak aligned to the NNW and SE in which eruptive fissures are located. The presence of a system of eruptive fissures and fractures associated with a major shield volcano is similar to that operated by the Puna Geothermal Project in Hawaii and could therefore accommodate an exploitable reservoir at suitable drilling depths. The presence of fumaroles, hydrothermal alteration and solfatara on the northern flank of Karthala top, further supports the hypothesis of the existence of geothermal resources.

Figure 66. Karthala geothermal prospect location and interpreted extension of potential resource area (Source: Houmadi et al., 2017).



Following the KenGen survey, an exploration project was conducted by the Gov. of the Union of Comoros through the Geological Bureau of Comoros, in partnership with the African Union and UNDP and with the technical assistance of the Gov. of New Zealand (MFA&T). Surface exploration studies consisted in a geochemical survey carried out in November 2014, and a geophysical survey conducted in July-August 2015, consisting in 80 magnetotelluric and 208 gravity measurements. The results highlighted a potential resource area of 4.1 km^2 in the north of the caldera located at the top of Karthala volcano, with estimated reservoir temperature up to 270°C. The geothermal potential was estimated at more than 40 MW. This phase of surface exploration was financed largely by a GRMF grant under the 2nd Application Round.

Based on the developed conceptual model, 3 exploratory wells were targeted, one vertical and two directional located in two different well pads at elevations of 1,700-2,000 m asl and bottom hole at elevations in the order of -400 m asl. Exploratory drilling is planned within the **Comoros Geothermal Project** conducted by the Gov. of the Union of Comoros in partnership with UNDP and NZ MFA&T (Houmadi et al., 2017). A grant from GRMF has been secured for the drilling of two exploratory wells of 2,500 m depth under the 3rd Application Round. UNDP has also secured funds through the Global Environment Facility (GEF). Technical assistance for ESIA, infrastructure assessment and project management were already secured in 2017.

In support of the sustainable geothermal development in the Comoros, UNDP has published in Sep. 2019 a Request for Proposals under GEF for the Recruitment of an international consulting firm accompanied by national consultants to update **the renewable energy policy in the Union of the Comoros**. An international consulting firm, accompanied by national consultants, will revise the legal framework of the energy sector. in order to adapt it to the new orientations of the Government. The project is structured in 3 components:

- 1: Policy, Regulatory, Legislative and Financial Instruments of "Derisking" for the Development of Geothermal Energy.
- 2: Preparation and development of geothermal energy upstream.
- 3: Knowledge Management and Investment Promotion.

UNDP has also advertised in Sept. 2019 an open job position for an **International Consultant** "Senior Technical Advisor" for the Sustainable Development in the Comoros through the promotion of geothermal energy resources. The Technical advisor will be responsible for assisting the Project team in the preparation of the Work Plan and the smooth implementation of the Work Plan in accordance with the UNDP Implementing Regulations.

According to the Comoros Geothermal Project planning (Houmadi et al., 2017), exploratory drilling was expected to take place in 2018, but at present no drilling tender was issued for the planned 3 exploratory wells. Works are on-going to assess port facilities, existing road network and access to the proposed drilling sites, and to review the options for drilling water supply (Anlil-Wafa et al., 2020).
Despite this delay, it is really important that from the beginning the Comoros Geothermal Project was planning to perform all the stages required from exploratory drilling to the installation and operation of the power plant. This should give more chances that full development will actually take place, while in several other cases development stages performed by different organizations with changing funding sources led to extremely long geothermal developments, with active phases separated by long stand-by.

The final project goal is to develop the inferred geothermal reservoir north of Karthala volcano to a potential of 10 MW, with 2x5 MW units. This potential would cover the base load of Grande Comore island, while a 5 MW Solar PV plant is envisaged to cover most of the electric energy needs during sunny hours (Houmadi et al., 2017). Diesel generators shall cover a small fraction of the overall electric energy consumption. Increasing the exploitation of inferred geothermal potential, estimated at some 40 MW, above 10 MW would make sense looking at the future increment of electric needs on Grande Comore island and to the interconnection through submarine cables of the other islands of the archipelago. The limited electric consumption of the two smaller islands and the non-negligible distance do not seem to justify the related investment.

The AGID data bank of ARGeo reports about the national organizations active on the geothermal development in Comoros, as shown in **Table 20**. NEC is the electric power utility which would produce and distribute the electric energy. MOE is in charge of the planning of geothermal sector development, while the Geological Survey of Comoros is in charge of exploration activities.

Table 20. AGID -Comoros Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/comoros.php)

Organization	Country	Name	Status
MOE-COMOROS	Comoros	Ministry of Energy, Mines, Industry and Handicrafts	Planned
NEC-Comoros	Comoros	National Electricity Company-Comoros	Active

3.7 Uganda

Uganda (The Republic of Uganda) is located at the north end of the Western Branch of EARS and is crossed NS on its western part by the Rift Valley (**Figure 67**). Uganda experienced a population growth from 5.2 M in 1950, to 23.6 M and 45.7 M in 2000 and 2019, respectively. The GDP rose from 6.19 B USD in 2000 to 20.19 and 28.5 B USD in 2010 and 2019. About 76% of the people live in rural areas and is still employed mainly in subsistence agriculture. The access rate to electricity increased from 8.17% in 2000 to 22% in 2017, with an acceleration after 2010 when it was at 12.1%. (https://www.macrotrends.net/countries/UGA/uganda/electricity-access-statistics).

The above figures are reflected in the TPES by source of generation shown in **Figure 68** with an almost unchanged situation from year 2000 to 2008 (IEA, 2010). Energy supply was dominated by Biomass (firewood, charcoal and crop residues) with a contribution of Oil (increased from 4 to 6%) which was totally imported, and a small contribution from Hydro (1%). The electricity consumption was about 40 kWh/capita in 2009 and it is now at 215 kWh/capita, still below the sub-Saharan Africa average. At present, about 90% of the total primary energy consumption is generated through biomass, which can be separated in firewood (78.6%), charcoal (5.6%) and crop residues (4.7%). Electricity is contributing only 1.4% to the national energy balance while oil products, which are mainly used for transport and thermal power plants, account for the remaining 9.7%. Wood fuels are largely used for cooking in rural areas while charcoal mostly provides for the cooking needs of the urban population. High demand for wood fuels used inefficiently results in overuse and depletion of forests.

Concerning electricity generation, Uganda has an installed capacity of 1,161 MW, mostly consisting of hydropower (920 MW) (Bahati and Natukunda, 2020). The actual total electricity capacity is 895 MW and the country's peak demand is about 620 MW, allowing at present the export of some electric energy to neighbouring countries. Mainly resulting from a prominent GDP growth of around 6% during the past decade, electricity demand has been growing at an average of 10% per annum. In the past years this led to occasional load shedding since the supply did not increase proportionally.

Uganda politically and economically reformed its energy sector including a new legal and regulatory framework based on which the previously vertically integrated monopoly, Uganda Electricity Board, was unbundled leading to public private partnerships. The Government provides an enabling environment for private sector investments in generation and distribution of electricity while transmission above 33 kV remains a public function through the Uganda Electricity Transmission Company Ltd (UETCL). The Electricity Regulatory Authority (ERA) was established to license and regulate operations of all electricity operators, and the Rural Electrification Agency (REA) was put in place to ensure that rural electrification, which in most cases is not commercially viable, is accelerated to achieve set targets. (https://energypedia.info/wiki/Uganda_Energy_Situation#Introduction).

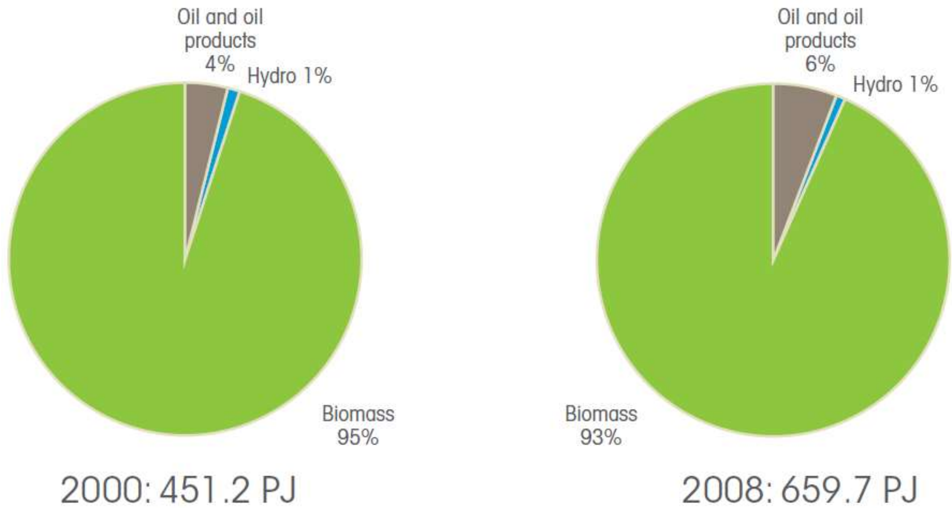
Uganda owns abundant energy resources, which are fairly distributed throughout the country. These include hydro, biomass, solar, geothermal, peat and fossil fuels. The energy resource potential of the country includes an estimated 4,500 MW of hydro power, 450 to 1,500 MW of geothermal, 1,650 MW of biomass cogeneration, 460 M t of biomass standing stock with a sustainable annual yield of 50 M t, an average of 5.1 kWh/m^2 of solar energy, and about 250 Mtoe of peat (800 MW). In addition, petroleum in an estimated amount of 6.5 billion barrels, of which 1.4 billion barrels are recoverable, has been discovered in the western part of the country. (https://energypedia.info/wiki/Uganda_Energy_Situation#Introduction).

In March 2019, the Gov. of Uganda commissioned a 183 MW power plant at Isimba and is contructing a 600 MW power plant at Karuma all along the River Nile (Bahati and Natukunda, 2020). The Karuma power plant is expected to raise the installed capacity to over 1,800 MW by 2020. In the long-term, the Government of Uganda (GoU) will develop Ayago (840 MW) and Oriang (392 MW) downstream Karuma on the River Nile.

Geothermal energy potential in Uganda was estimated at 450 MW (Omenda, 2018b), recently updated to 1,500 MW (Bahati and Natukunda, 2020). Exploration for geothermal energy has been in progress since 1993. So far, four potential areas all situated in western Uganda, in the Western Branch of the EARS have been identified for detailed exploration. The four potential areas are Katwe-Kikorongo, Buranga, Kibiro and Panyimur. The current study results indicate that the inferred temperature varies between 120°C and 250°C which is sufficient for electricity generation and for direct use in industry and agriculture. The rest of the geothermal areas of Uganda are at a preliminary level of investigation and results are expected to be soon available as basis for their prioritisation for detailed surface exploration (https://energypedia.info/wiki/Uganda_Energy_Situation#Introduction).

Figure 67. Map of Uganda (Source: https://www.britannica.com/place/Uganda)

Figure 68. Total Primary Energy Supply (TPES) by source for Uganda, in 2000 and 2008 (excluding electricity trade) (Source: IRENA, 2010)



The Western Branch of the EARS is an active intra-continental rift system, comprising an axial rift with a succession of tectonic basins (rift valleys, grabens) linked by intra-continental transforms and segmented by transfer zones and accommodation zones. On the surface, the main tectonic features are normal faults but there are also strike-slip faults, oblique-slip faults and reverse faults. The results of exploration studies performed so far in the four most promising prospects in Uganda indicate that the geothermal activity appears to be related to fault-controlled deep circulation systems, rather than magmatically heated systems associated with volcanoes, which is consistent with the revised view on geothermal prospects in the Western Branch of the EARS (Bahati and Natukunda, 2020). As proposed by Alexander et al. (2016c), most geothermal prospects along the Western Branch of the EARS are fault-controlled, similar to the large number of operating and drilled fields in the US Basin and Range region and in the Menderes Graben in Turkey. These geothermal systems are typically smaller than those in the volcano-hosted systems of the Eastern Branch of the EARS, although it is likely that there are also fault-controlled systems in the far northern and southern sectors of the Eastern Branch (Heat et al., 2018).

Experience from the Basin and Range region of the US and from Turkey has shown that medium and even low enthalpy geothermal resources can be economically viable. High enthalpy resources have been the focus in East Africa to-date. The key aspects of fault-controlled systems that can lead to this outcome in East Africa include: shallower reservoirs and lower drilling costs; local markets for power and direct use linked to economic development initiatives; and use of standard ORC generation plants, which can shorten development timescales.

The East Africa Geothermal Energy Facility (EAGER) has gained experience with fault-controlled systems conducting structural mapping and interpreting geophysical survey results in the Western Branch of the EARS with TGDC (Tanzania) and GRD (Uganda). The new achieved understanding has implications for both geological exploration and the identification and prioritization of prospects in Uganda, such as Kibiro and Panyimur (Heat et al., 2018). The Western Branch of the EARS has been recognized to more likely host <200°C deep-circulation types of geothermal reservoirs rather than the >230°C magmatically-heated geothermal reservoirs that have been drilled and developed in the Eastern Branch of the EARS.

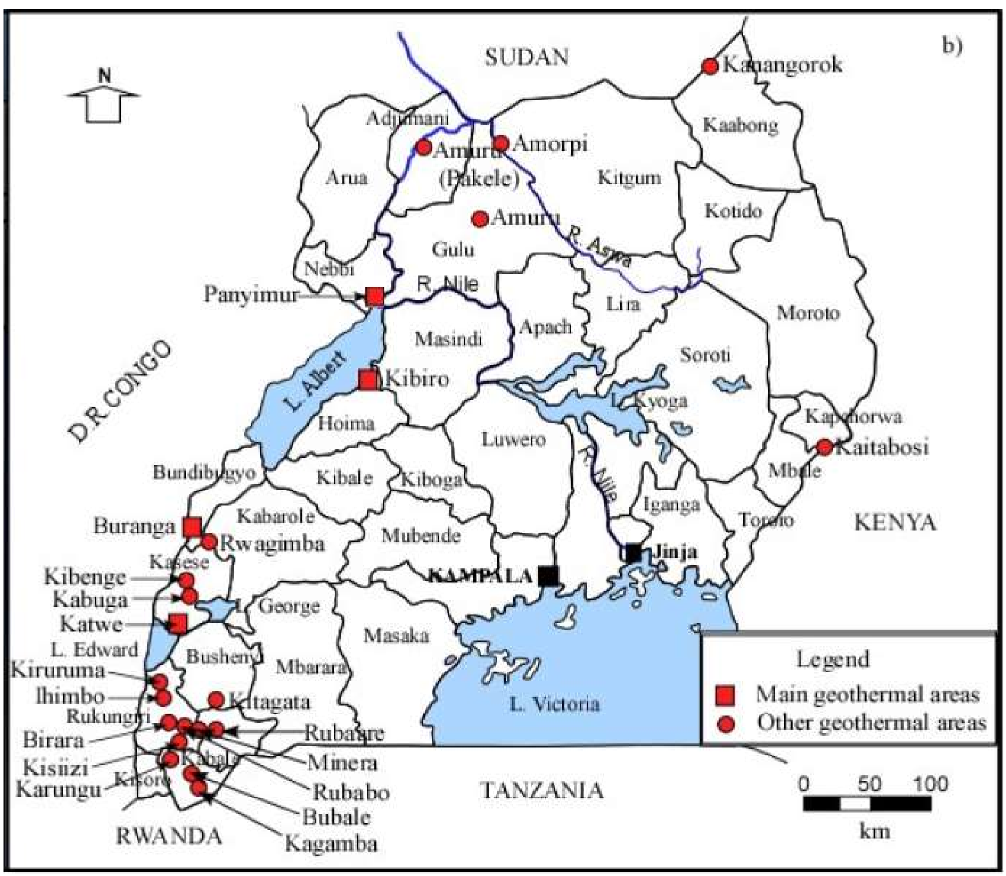
Reconnaissance surveys on Ugandan hot springs started in 1921 by the geological survey of Uganda and the first results were published by Wayland (1935). In 1973, as a result of the oil crisis, an attempt was made to initiate a geothermal project with United Nations support, but this did not materialise due to the political turmoil in the country.

The Geothermal Energy Exploration Programme, phase 1 (1993-1994), was the first serious geothermal exploration carried out on the three at the time highly ranked prospects (Kato, 2013). The project was funded by the GoU, UNDP, OPEC, and Gov. of Iceland through ICEIDA. It was implemented by DGSM and executed by the Department of Development Support and Management Services of United Nations. Work included geological, geochemical and isotopic surveys in Kibiro, Katwe-Kikorongo and Buranga (Ármannsson, 1994). The results warranted more field investigations to up-grade the working model to a pre-feasibility status.

The Isotope Hydrology for Exploring Geothermal Resources project, phase-1 (1999-2003), was founded by IAEA together with MEMD with the aim of refining the conceptual working models of Kibiro, Buranga and Katwe-Kikorongo prospects using isotopes (Bahati et al., 2005). This was a follow up of the UNDP-ICEIDA project of 1993-1994.

The 4 most promising geothermal prospects, identified by reconnaissance and surface studies, Katwe, Kibiro, Buranga and Panymur, are located within the Rift Valley in western Uganda as shown in **Figure 69**. Four additional areas have been considered for detailed surface exploration and they include Rubaare, Kitagata, Ihimbo, and Kanangorok (Kato, 2013).

Figure 69. Location of known geothermal areas in Uganda (Source: Bahati et al., 2005)



From 2015 to 2018 exploration focused on structural geology, geochemistry and geophysics and development of subsurface conceptual models. The detailed exploration was carried out by the MEMD with technical support from the East African Geothermal Energy Facility (EAGER) sponsored by the United Kingdom Department for International Development (DFID) (EAGER-GRD, 2018). The study developed conceptual models for Kibiro, Panyimur and Buranga prospects.

Following three and a half decades of geothermal exploration at **Katwe** that has focused on volcanic models for the geothermal system (Gíslason et al., 2010), new interpretations of existing data and new data acquired and processed by GRD with the support of EAGER, indicate that the geothermal resource at Katwe is likely to be a deep circulation system located near Lake Kitagata (Isabirye et al., 2020). New structural mapping has confirmed that the resource is associated with fault geometry likely to promote the formation of deep fracture permeability and deep circulation. Further evaluation of the spring, lake and borehole fluid geochemistry, has concluded that the hot springs at Lake Kitagata are the only thermal fluids in the Katwe area and their geochemistry indicates a probable resource temperature in the range 107 - 136°C. Consequently, EAGER and GRD have developed several alternative deep circulation conceptual models for the geothermal activity at Kitagata that are analogous to US Basin and Range type systems (Hinz, 2018). The ambiguity regarding these models, one intersection and one step-over, could be reduced by targeting two temperature gradient wells to test whether a hotter system is likely to be found to the SSW of Lake Kitagata. Additional geochemical sampling for water and gas chemistry and stable isotopes has been recommended by Haizlip (2018) to support a more complete understanding of the source of the Kitagata hot spring fluids. Soil gas surveys and 2 m shallow temperatures probe surveys could be used to assess evidence of shallow heating not directly associated with hot springs. Following the acquisition of new data, conceptual models should be updated to facilitate decisions, for example, for targeting TGH drilling if that proves to be compatible with the special status of the area.

Kibiro geothermal prospect is located on the eastern escarpment of the Western Branch of EARS in western Uganda, in the administrative district of Hoima along shores of Lake Albert (Mawejje et al., 2020). Exploration at Kibiro started in 1993 with the above cited DGSM project performed in cooperation with UNDP (Gislason, 1994). The project was primarily focused on geochemistry and geology: the chemistry of the spring water indicated sub-surface temperatures in the range of 200°C (Ármannsson 1994). No clear indication was found on the nature of a heat source, but the main attention for a reservoir was directed towards the thick sediments of the tertiary rift system.

In 1999, the cited DGSM project in co-operation with IAEA was initiated and completed in 2002 (IAEA, 2003). Project findings regarding the Kibiro area showed that the main source of recharge is meteoric water, originated from higher elevation than in the immediate escarpment area, pointing inland away from the rift. The isotope geothermometers pointed towards lower reservoir temperature than conventional geothermometers (140°C), and the isotope research implied water-rock interaction, old age of the system, or low water/rock ratio.

In 2004 and 2005 ICEIDA together with DGSM conducted surface exploration studies at Kibiro (Gislason et al 2004). The surveys included magnetics, gravity and TEM resistivity surveys. A very low resistivity anomaly (<1 ohm m) was detected in the Precambrian metamorphic rocks. The low resistivity anomaly was misinterpreted to represent a geothermal reservoir in the basement rock and the Kibiro thermal springs to be its outflow. Based on the above conclusions, six temperature gradient wells were drilled in the basement rock of the escarpment south of Kibiro. The results of the drilling showed low, generally conductive temperature gradients typical of other ancient continental shields (e.g., the Canadian and South African shields). The conductive gradients and different water levels in most wells indicated a general lack of permeability in the Precambrian, except in isolated fracture systems. The well cuttings demonstrated that the low-resistivity features in the basement rock were not caused by a currently active magmatic heat source but rather by relict conductive mineralization (Árnason and Gislason, 2009).

In 2012 DGSM carried out geological investigations over a low magnetic anomaly NE of Kibiro hot spring. Altered ground with silica, clayey grounds and calcite were discovered. In 2013 further investigations were made and gap between magnetic anomaly and Kibiro hot springs filled up (Mawejje et al., 2013). Based on distribution of manifestations, it was concluded that Kibiro geothermal field is a fault controlled geothermal system, and that the upflow is through the main fault scarp.

A change on exploration approach suitable for fault controlled geothermal systems was considered, including detailed structural studies with benchmarks from analogous geothermal systems, such as the great basin of USA. A UNEP ARGeo project was conducted in 2015 and 2016 to carry out field geologic investigations, a review of the geochemistry data, a review of oil exploration data from nearby in the lake basin, a review of existing geophysics data and acquisition of new TEM and MT data, a soil gas and soil temperature survey, development of conceptual models, resource capacity estimates, and selection of TGH drill targets (Mawejje et al., 2020). The geochemistry analyses conducted in conjunction with the geologic structure, stratigraphy, and reflection seismic information suggested that the Kibiro hot springs are most likely associated with a 115 to 150°C fault-hosted up-flow with no direct magmatic heating and that the deep geothermal reservoir is probably hosted in the sedimentary rocks above the pre-rift basement beneath Lake Albert (Alexander et al., 2016c).

DGSM in collaboration with EAGER expert performed a review of available data and further detailed structural mapping to refine the DGSM-UNEP 2016 conceptual model and improve on the temperature gradient hole drilling targets and planning (Mawejje et al., 2020). Updating of the previous conceptual model with new data and findings confirmed the Kibiro prospect shares the common patterns associated with many deep circulation fault systems as those exploited in the Basin and Range region of the USA. TGH location was revised and the number of TGH to be drilled increased from 6 to 8. According to the final updated conceptual model, two reservoirs have been inferred at Kibiro prospect (Mawejje et al., 2020): a deep seated higher temperature one whose cap rock is thought to be non-permeable shales below the lacustrine sediments, with up-flow mainly controlled by the main fault; a shallower reservoir within the clastic delta deposits whose cap rock is interpreted to be a flat layer of smectite clay. The shallow reservoir may be productive enough and utilized. It can pose a risk during drilling of deep wells targeted to intercept the deeper reservoir. Next exploration step planned is the drilling of new targeted TGH.

The GRD has been awarded a grant from the 5th Application round of GRMF for surface studies in the Kibiro prospect (GRMF, 2018).

The **Buranga** geothermal prospect is located in Bundibugyo and Ntoroko districts at the north-western base of the Rwenzori Mountains in the Western Branch of the EARS (Natukunda and Bahati, 2016). Exploration activities at Buranga were performed within the already cited projects:

- the Geothermal Energy Exploration Programme, phase 1 (1993-1994) (Kato, 2013), funded by the GoU, UNDP, OPEC, and Gov. of Iceland through ICEIDA. Work included geological, geochemical and isotopic surveys.
- the Isotope Hydrology for Exploring Geothermal Resources project, phase-1 (1999-2003), founded by IAEA together with MEMD with the aim of refining the conceptual working model of Buranga prospect using isotopes (Bahati et al., 2005).
- the EAGER project in 2015-2018 in collaboration with MEMD sponsored by the United Kingdom Department for International Development (DFID) (EAGER-GRD,

2018). Activities were focused on structural geology, geochemistry and geophysics and development of subsurface conceptual model.

Subsurface temperatures of 120-150°C are inferred by geothermometry applied to fluid sampled at the Buranga impressive geothermal surface manifestations. These temperatures, if confirmed by deep drillings, are enough for electric power generation using ORC plants. Isotope studies indicate the source of the geothermal fluids at Buranga to be from high elevations in the Rwenzori Mountains, with subsurface temperatures predicted at around 200°C. The reservoir is inferred to be located in fractured granitic gneisses, with faulted and fractured basement of the Rwenzoris providing adequate permeability for reservoir recharge (Natukunda and Bahati, 2016). Further surface exploration activities as well as drilling of TGH and siting and targeting of exploration wells have been recommended as follow up for the Buranga prospect.

GIDS Consult Ltd. has been awarded a grant from the 5th Application round of GRMF for surface studies in the Buranga prospect (GRMF, 2018).

The **Panyimur** geothermal prospect is located in Pakwach District, West Nile Region, to the N of Lake Albert. Panyimur appears to be a fault-controlled system that is associated with a 1.5 to 2 km-wide step-over linking two NNE-striking faults (Bahati and Natukunda, 2018). The surface manifestations are hot springs distributed in three clusters along a 1.25 km-long segment of the Lower Fault, with highest temperature of 70°C. The subsurface temperature, predicted by geothermometry, is in the range of 110 – 140°C suitable for use in electricity production and direct use in industry and agriculture (Ármannsson et al. 2007). Geophysical studies carried out in 2015 used gravity and magnetics methods which clearly delineated the major NE-SW trending fault, but did not delineate the perpendicular NW-SE cross faults. Geophysical investigations using MT/TEM were performed in 2016.

The conceptual model proposed for Panyimur based on MT results includes the downflow and up-flow in fault/fracture hosted permeability within the damage zone and fault plays directly associated with the Lower fault. The inferred isotherm pattern assumes that a deep 150°C up-flow ascends along the Lower Fault and outflows at 115 to 125°C in a sand/gravel aquifer at about 300 m depth, and also indirectly outflows at 75°C into a shallower and thinner sand-gravel aquifer at about 70 m depth. The water chemistry re-equilibrates in the outflow aquifers to be consistent with the chemistry of the hot springs. Targeting a deep geothermal reservoir was not yet recommended (Bahati and Natukunda, 2018). The recommendations included:

- Drill 5 to 8 TGW to a depth of 200-300m to confirm the existence of a geothermal reservoir.
- Acquire new TEM soundings and complete an integrated reflection seismic and MT cross section through the Amoropii hot springs.
- Update the conceptual models.
- Targeting and planning of slim hole or full-size hole drilling.

The GRD has been awarded a grant from the 5th Application round of GRMF for surface studies in the Panyimur prospect (GRMF, 2018).

The AGID data base lists 3 geothermal sites (**Table 21**), while the 4th most studied geothermal prospect, Panyimur, is missing.

Table 21. AGID -Uganda Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/uganda.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
Kibiro	Uganda			Yes	Yes	No
Buranga	Uganda			Yes	Yes	No
Katwe	Uganda			Yes	No	No

The AGID data bank of ARGeo reports about the national organizations which are active on the geothermal development in Uganda, as shown in **Table 22**.

The Ministry of Energy and Mineral Development (MEMD) is the lead agency in the energy sector (https://www.energyandminerals.go.ug/). The Ministry is responsible for policy formulation, promotion, coordination, monitoring and evaluation. MEMD is also responsible for initiating legislation in the energy sector. In 2014 a Geothermal Resources Department (GRD) was created within MEMD to focus on exploration, promotion, licensing and management of geothermal resources.

Rural Electrification Agency (REA, http://www.rea.or.ug/) functions as the secretariat to the Rural Electrification Board, which realizes MEMD's rural electrification plans. REA controls public funds for the subsidization of rural electrification projects. Electricity Regulatory Authority (ERA, https://www.era.or.ug/) is in charge to issue licenses for the generation, transmission, distribution or sales of electricity (https://energypedia.info/wiki/Uganda_Energy_Situation#Introduction). ERA has also the mandate to give permits for feasibility studies and licenses geothermal power plants, regulates geothermal power plant operators and sets the tariff for electricity generated from geothermal energy (Kato, 2013).

The Uganda Electricity Transmission Company Ltd. (UETCL, https://www.uetcl.com/) is the bulk supplier and single buyer of power for the national grid in Uganda. It purchases all independently generated power in the country and imports electricity from neighbouring countries. The biggest company empowered to trade and supply electricity at 33kV and below is Umeme Ltd, which leased the assets of the formerly government-owned distribution company (Uganda Electricity Distribution Company Ltd - UEDCL). There are some mini-grid distribution systems and one off-grid generation and distribution company (West Nile Rural Electrification Company Ltd) (https://energypedia.info/wiki/Uganda_Energy_Situation#Introduction). The National Environment Management Authority (NEMA, https://www.nema.go.ug/) coordinates processes of environmental impact assessments for geothermal activities, monitors and audits geothermal activities, and issues guidelines for strategic environmental assessment (Kato, 2013).

Table 22. *AGID -Uganda Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/uganda.php)*

Organization	Country	Name	Status
MEMD	Uganda	Ministry of Energy & Mineral Development	Active
ERA	Uganda	Electricity Regulatory Authority	Active
UETCL	Uganda	Uganda Electricity Transmission Company Ltd	Active

Geothermal exploration activities performed on the 4 most promising areas allowed to realize that geothermal prospects along the Western Branch of the EARS in Uganda are fault-controlled, similar to the large number of operating and drilled fields in the US Basin and Range region and western Turkey. These geothermal systems are typically smaller than those in the volcano-hosted systems of the Eastern Branch of the EARS, and more likely host geothermal systems with temperature <200°C, rather than systems with temperature >230°C such as those drilled and developed in the Eastern Branch of the EARS. A change on exploration approach suitable for fault controlled geothermal systems was then considered and applied in Uganda, improving the effectiveness of exploration surveys and the understanding of studied geothermal prospects.

Until now all the studied prospects have not yet reached an exploration stage suitable for the targeting and drilling of deep exploration wells. Expected temperatures are suitable for electric power generation using ORC plants, subject to the confirmation of the existence of reservoirs suitable for industrial exploitation.

Despite the willing and efforts of the GoU to utilize the geothermal resources of the country, results achieved so far do not allow to hypothesize that geothermal energy will be soon available to contribute to the base load of the national electric network. It seems also that even if exploration will be finally successful, geothermal energy will not be able to give a remarkable contribution to the future electric energy generation in Uganda, which will be probably dominated by Hydro with the contribution of other renewables.

3.8 Rwanda

Rwanda (The Republic of Rwanda) is located between Uganda and Burundi along the Western Branch of EARS and is crossed NS on its western part by the Rift Valley (**Figure 70**). Rwanda experienced a population growth from 2.2 M in 1950, to 7.9 M and 12.6 M in 2000 and 2019, respectively. The GDP rose from 1.81 B USD in 2000 to 5.78 and 9.51 B USD in 2010 and 2019. About 83% of the people live in rural areas and is still employed mainly in subsistence agriculture. The access rate to electricity steadily increased from 6.2% in 2000 to 34.1% in 2017, with an acceleration after 2013 when it was at 15.2%. (https://www.macrotrends.net/countries/RWA/rwanda/electricity-access-statistics). The current installed generation capacity is 221 MW with 51% electricity access of which 13% off-grid and 38% on-grid (Rutagarama, 2020).

The above figures are reflected in the TPES by source of generation shown in **Figure 71** with an almost unchanged situation from year 2000 to 2008 (IEA, 2010). Energy supply was dominated by Biomass (firewood, charcoal and peat) with a contribution of Oil (declined from 11 to 9%) which was totally imported, and a small contribution from Hydro (0.5-0.2%). The electricity consumption was about 22 kWh/capita in 2009, which was well below the East Africa average. Currently, the 221 MW total installed capacity is based on the following generation technology mix: 45% from Hydro resources, 25% from thermal sources, 14% from natural gas (from resources under lake Kivu shared with the DRC), 7% Peat and 6% Solar (Rutagarama, 2020). Additional 3% is from imports.

Until 2004, Rwanda depended on a single energy source (Hydro) whose limited capacity relied on an old network with technical and commercial losses of around 30%, much of which is attributed to the lack of investment in the sector for the last 25 years. In 2004-2006, Rwanda has suffered from acute electricity supply shortage and severe load shedding. Its installed generation capacity has been severely constrained by regional drought leading to a rapid draw down of the reservoirs. Drought has also affected Kenya, Tanzania and Uganda, leaving Rwanda with no possibility of sourcing electricity from its neighbours (https://energypedia.info/wiki/Rwanda_Energy_Situation #Introduction).

In late 2004, the Government of Rwanda (GoR) was forced to rent diesel generators from private companies at a high cost and this in addition to high fuel costs increased tariffs by over 100%. In order to realize its ambition of becoming a middle-income country, the GoR together with the private sector is endeavouring to scale up the energy production and distribution so as to make the energy sector competitive in the sub-region. The GoR is exploring mechanisms to improve modern energy services in rural areas, by implementing promising options for rural energy supply, such as solar energy, wind energy and extension of the grid to rural areas.

Rwanda is planning to expand from 221 MW of grid power in 2018 to 556 MW in 2024 and may import as much as needed from neighbouring countries. The focus is on developing the existing potential energy sources from peat, solar, shared hydro sites and methane gas. In addition, it is installing small solar units throughout the country to ensure electricity to buildings not connected to the national grid, or to help deal with power outages. Currently, the government plans to bring electricity access to 100% of the population by 2024, as opposed to 51% in 2019.

Geothermal Energy Association (GEA, 1999) estimated a geothermal potential in Rwanda from 170 to 340 MW. This estimation was revised down to 90 MW by JICA in 2015 (JICA, 2015b). In Rwanda geothermal energy is a main policy priority and formed a significant part of the 7-year electricity development strategy including a very ambitious action plan targeting 150 MW of generation capacity by 2017 (which would have represented up to 50% of total generation). A Geothermal Act and a geothermal exploration and development paper have been drafted although a proposal for a feed-in-tariff for geothermal still needs to be developed.

Figure 70. Map of Rwanda (Source: https://www.britannica.com/place/Rwanda)

The Western Branch of the EARS is an active intra-continental rift system, comprising an axial rift with a succession of tectonic basins (rift valleys, grabens) linked by intra-continental transforms and segmented by transfer zones and accommodation zones. On the surface, the main tectonic features are normal faults but there are also strike-slip faults, oblique-slip faults and reverse faults. The 4 most promising geothermal prospects, initially identified by reconnaissance studies, are located within the Rift Valley in the NW and SW Rwanda as shown in **Figure 72**.

Figure 71. Total Primary Energy Supply (TPES) by source for Rwanda, in 2000 and 2008 (excluding electricity trade) (Source: IRENA, 2010)

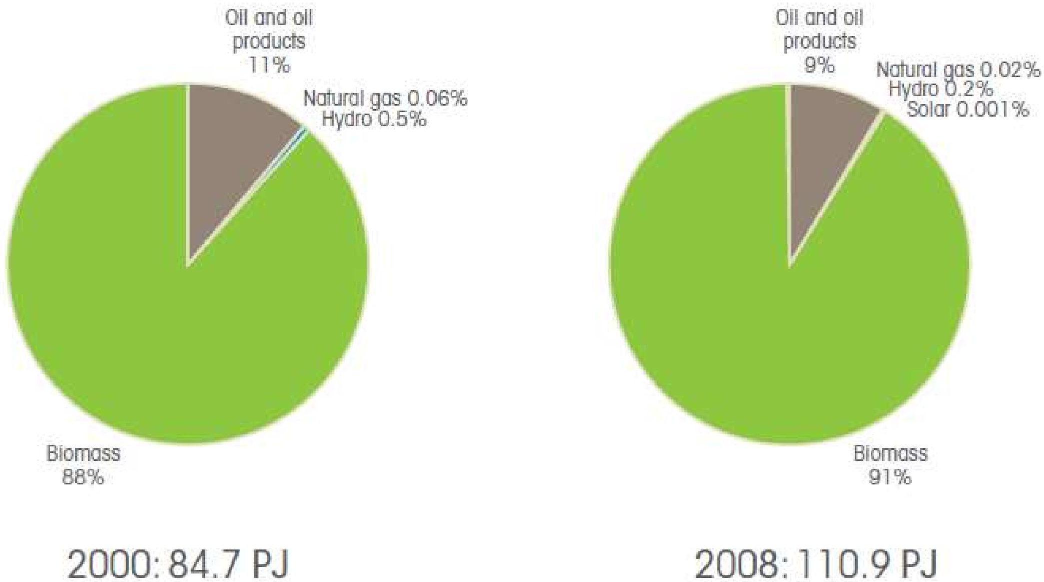


Figure 72. Location of the 4 most promising geothermal prospect in Rwanda (Source: JICA, 2015)

The geothermal exploration of Rwanda was initiated in 1982 by BRGM (French Bureau of Geology and Mines). They conducted geochemical surveys at Mashyuza (Bugarama), Gisenyi, Kibuye, Ntaresi and Musanze, identifying Gisenyi and Bugarama as potential sites for geothermal development with estimated reservoir temperatures of over 100ºC (Demange et al., 1983). Later, Chevron studied reservoir temperatures using geothermometry of the hot springs in Bugarama and Gisenyi and estimated the geothermal reservoir temperatures to be more than 150°C (Newell et al., 2006).

In 2008, BGR collaborated with KenGen, ISOR and ITER (Institute for Technology and Renewable Energies) of Spain to conduct geochemical, geophysical and soil gas surveys in Gisenyi, Karisimbi and Kinigi (Egbert et al., 2009). They concluded that: (1) a geothermal system with temperature over 200°C is located south of Karisimbi volcano; (2) the temperature of the geothermal system near Lake Karago is 150 to 200°C; (3) the depth of heat source in Karisimbi is about 5 km.

In 2009, KenGen conducted additional surface surveys (geophysical and geochemical) and an environmental impact assessment south of Karisimbi volcano (Mariita et al., 2010). In a workshop held in Kigali in February 2010, a geothermal conceptual model based on those results and drilling targets for three wells were discussed. It was also reported that the geothermal resource potential of the whole of Rwanda was estimated to be 120 MW (±50 MW) from the averaging of the results based on the counting of volcanoes, natural heat flux, soil CO_2 flux and a Monte Carlo assessment. 50 MW was considered as a reasonable initial target for geothermal generation in Rwanda in the next 5-6 years (Rutaragama, 2010). In 2010, KenGen conducted geophysical (MT and TEM), geochemical (soil gas: CO_2, mercury and Radon) and a hydrogeological survey (Mariita et al., 2010). They concluded that the geothermal system is possibly distributed to the regions around the southern slopes and trends to the southeast through the town of Mukamira toward Lake Karago. Therefore, it was recommended that the exploration wells should be drilled directionally ranging between 2,000 and 3,000 m in depth to intersect as many structures as possible.

In 2011, MININFRA re-evaluated the geothermal resource potential of Rwanda as over 700 MW in total and 300 MW in the NE area. However, these values were calculated by simply multiplying the number of production wells per unit area (10 wells per km^2 was assumed for all areas) by the output from one production well (4 MW per well was assumed), where the promising geothermal areas were determined from the geophysical surveys. Therefore, this evaluated potential is not corroborated by enough specific field data.

From 2011 to 2012, IESE (Institute of Earth Science and Engineering) of New Zealand conducted geological, geochemical, and geophysical (MT, TEM and CSAMT) survey, as part of a microseismic and heat flow study with boreholes at Kinigi, Gisenyi and Karisimbi (Shalev et al., 2012). As a result, a geothermal conceptual model regarding geological structures and geothermal fluid flow was elaborated, and targets for three vertical exploratory wells were proposed to confirm the reservoir.

In April 2012, the first validation workshop was held to verify previous survey results and enable the elaboration of a geothermal conceptual model of the area around Karisimbi and the targeting of three exploratory wells. As a result, the geophysical analytical results were thought to be insufficient. In January 2013, another validation workshop was held by UniServices, GDC, RG, KenGen and EWSA (now EDCL) to verify the re-analysed results. They can be summarized as follows: (1) the resistivity model around Karisimbi volcano consists of a high resistivity layer (recent volcanic), a low resistivity layer (may be the clay cap) due to hydrothermal alteration of low temperature clays and a higher resistivity layer (reservoir) due to a higher degree of hydrothermal alteration, (2) there is a deeper low resistivity layer (heat source) which becomes shallower toward Karisimbi volcano and dips sharply to the south, (3) drilling targets were confirmed: drilling should be directional toward Karisimbi volcano targeting the NW and NE trending interpreted fractures and go to a depth of 3,000m.

JICA supported the preparation of an electricity development plan for sustainable geothermal energy development and its integration into the Electricity Master Plan. This master plan (JICA, 2015b) gives estimates of the identified potential geothermal prospects based on data existing at the time, with an action plan for exploration and development of each prospect. The study evaluated a maximum geothermal potential of 90 MW for the country.

Drilling for the first geothermal exploratory well KW-01 in the southern slopes of **Karisimbi** volcano started on July 18, 2013, and finished on October 23, when it reached 3,015 m depth, followed by the second exploratory well KW-03 completed in March 2014 at 1,367 m. Wells drilling was financed by the GoR, with technical assistance prior of drilling financed by JICA, on-the-job training provided by ISOR through funding from ICEIDA, drilling supervision for the first well carried out by Reykjavik Geothermal (RG) and funded by NDF. Alteration mineralogy and measured temperatures in the two wells are consistent with normal continental geothermal gradient (i.e. ~30°C/km) conclusively demonstrating that there is not a geothermal reservoir under the southern slopes of Karisimbi (Rutagarama, 2020).

The **Kinigi** geothermal area is located to the east of Karisimbi. Detailed surface studies as well as an ESIA have been completed and supplementary studies were recommended to decide on the way forward for the exploration of this prospect. Additional geoscientific surveys to update the Kinigi geothermal conceptual model were funded by JICA and carried out in June 2015 by WestJEC. Remote sensing data analyses, volcanic rock sampling and gravity surveys were completed followed by the construction of a conceptual model. Results of the study were shared during a Technical Review Meeting (TRM) organized by UNEP-ARGeo and the Icelandic Ministry of Foreign affairs in May 2016. Additional studies to focus on summit of Sabyinyo and associated volcanic centres were recommended by the TRM but it was agreed that there is no conclusive sign of geothermal system in the Kinigi study area (Rutagarama, 2020).

In parallel to the above initiative, the GoR submitted an Expression of Interest to the GRMF for support in infrastructure and exploration drilling of slim holes in Kinigi. The Kinigi project was qualified for grant award for slim holes drilling in 2015, but considering the recommendations from the TRM, the procedure for grant award was subsequently suspended (Rutagarama, 2020).

The **Gisenyi** geothermal prospect is located south-west of Karisimbi. Hot springs of about 75°C are located in the prospect at the shores of Lake Kivu. Geoscientific investigations have been carried out in the area. Additional studies to complement existing data in the Gisenyi area was awarded to the Consortium SARL Geo2D - GDC funded by the EU. The preliminary results of the data collected were discussed during the TRM in May 2016 and additional geophysical and geochemical data were recommended. The findings of this study were presented in June 2017. The structural geology identified four areas of interest for geothermal detailed surveys: Kilwa (Area 1), Gisenyi (Area 2), Muti (Area 3) and Kanzanza (Area 4). Detailed geophysical and geochemical data collection were carried out in Area 1 and conclusions from the interpretation and synthesis of available geological, geochemical and geophysical data were presented. It appears that a shallow geothermal reservoir at 100°C is identified and a deep reservoir develops at a temperature of ~160°C with a deepest part at 200°C (GDC& SARL Geo2D, 2017).

Considering that the geometry of the reservoir could not be well defined due to the limitations of the geoscientific methods deployed and the available data, MT measurements and slim holes drilling at the fault and across the peninsula, were recommended to get information on the depth of the reservoir. In June 2018, the GoR submitted an application for grant for additional surface study for the Gisenyi geothermal prospect to the GRMF which was unsuccessful. Currently, The GoR is supporting the procurement of a consultancy firm to carry out additional detailed surveys of the area (Rutagarama, 2020).

The **Bugarama** geothermal prospect is located in the southern province of Rwanda. The geothermal manifestations in the area are hot and warm springs and travertine deposits. The highest spring temperature is about 55°C. A regional geothermal exploration study for Democratic Republic of Congo, Burundi and Rwanda, funded by EU and performed by Reykjavik Geothermal (RG), started in November 2013. Surface exploration and drilling of thermal gradient wells in the Rwandan part were completed and a conceptual model was developed. The conclusion of the study indicates that Bugarama is a typical low enthalpy system and no localized heat source is present. The predicted subsurface temperatures mainly based on silica geothermometers are in the range of 75°C to 115°C and the depth to the resource has been estimated to be ≥ 1100 m. Additional geoscientific surveys and a market study for direct uses in the surroundings of the site are recommended to cover the information gaps from this survey (Rutagarama, 2020).

The AGID data base lists only 2 geothermal sites (**Table 23**), despite both of them seem not to hold exploitable geothermal resources.

Table 23. AGID -Rwanda Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/rwanda.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
Karisimbi	Rwanda			Yes	Yes	Yes
Kinigi	Rwanda			Yes	No	No

The AGID data bank of ARGeo reports about the national organizations which are active on the geothermal development in Rwanda, as shown in **Table 24**. The Ministry of Infrastructure (MININFRA, https://www.mininfra.gov.rw/) is responsible for the overall coordination of activities in the energy sector and for the strategies, planning and monitoring of the implementation of the different programs. In particular, MININFRA has jurisdiction over geothermal development policy in Rwanda. The Ministry also plays an important role in attracting private sector investment and coordinating support of development partners.

The Energy, Water and Sanitation Authority (EWSA), which was responsible for the implementation of MININFRA programs, was divided in 2013 into two public companies, namely the Rwanda Energy Group Limited (REG, http://reg.rw/index.php?id=2) and the Water and Sanitation Corporation (WASAC, https://www.wasac.rw/home), which operate as commercial companies. REG is a state-owned holding company responsible for the import, export, procurement, generation, transmission, distribution and sale of electricity in Rwanda. It performs its functions through two wholly owned subsidiaries, (a) the Energy Utility Corporation Limited (EUCL, http://umurimo.com/mot/eucl) and the Energy Development Corporation Limited (EDCL, http://www.reg.rw/about-us/subsidiaries/edcl/). A Geothermal Unit within EDCL is handling geothermal development activities including surveys, analysis and well drilling.

Table 24. AGID -Rwanda Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/rwanda.php)

Organization	Country	Name	Status
MININFRA	Rwanda	The Ministry of Infrastructure	Active
EDPRS	Rwanda	Economic Development and Poverty Reduction Strategy	Active
REMA	Rwanda	Rwanda Environment Management Authority	Active

The exploration activities performed so far in Karisimbi and Kinigi failed to confirm the existence of active geothermal systems in both prospects. A low temperature reservoir (<115°C) is inferred to exist at Bugarama prospect, thus with temperatures at the lower extreme for energy generation even with ORC plants. Surface exploration at Gisenyi geothermal prospect suggested the possible presence of a shallow geothermal reservoir at 100°C above a deeper reservoir with temperature from ~160°C to 200°C, but additional MT surveys and the drilling of slim holes has been recommended to confirm the indication of surface exploration. Rutagarama (2020) concludes that the geothermal characteristics of the Western Branch of the EARS are yet to be well understood in order to apply adequate methodology for geothermal exploration in Rwanda.

Thus, the exploration activities performed so far shows that 3 of the 4 most promising prospects identified by the reconnaissance studies are actually not containing geothermal resources suitable for electric power generation. Only the surface exploration on Gisenyi prospect is suggesting that it is worth to continue with additional exploration activities. Despite the willing of the GoR to diversify the sources of electric energy generation by developing also geothermal resources, results achieved so far indicate that the known geothermal sites in the country have an overall limited potential and will not be able to give a remarkable contribution to the future electric energy generation in Rwanda, unless improved exploration approaches will be able to identify new promising prospects.

3.9 Burundi

Burundi (The Republic of Burundi) is located on the NE border of lake Tanganyka along the Western Branch of EARS and is crossed NS by the Rift Valley (**Figure 73**). Burundi experienced a population growth from 2.3 M in 1950, to 6.4 M and 11.8 M in 2000 and 2019, respectively. The GDP rose from 0.87 B USD in 2000 to 2.03 and 3.2 B USD in 2010 and 2019, being above about 3 B USD since 2015. About 87% of the people live in rural areas and is still employed mainly in subsistence agriculture. The access rate to electricity steadily increased from 2.1% in 2000 to 9.3% in 2017, but remains very low with respect to the average of sub-Saharan countries (https://www.macrotrends.net/countries/BDI/burundi/electricity-access-statistics).

The above figures are reflected in the TPES by source of generation shown in **Figure 74** with an almost unchanged situation from year 2000 to 2008 (IEA, 2010). Energy supply is dominated by Biomass (firewood, charcoal and peat) with a contribution of Oil (declined from 5 to 2%) which is totally imported, and a small contribution from Hydro (0.4-0.9%). The electricity consumption was about 23 kWh/capita in 2009, which is well below the East Africa average.

Installed electric power in the country is based on Hydro (8 dams operated by REGIDESO for a total of about 50 MW), Fossil Fuels (35.5 MW mostly from private thermal plants) and Solar PV (2.9 MW), for a total installed capacity of 88.4 MW (Wakana, 2020), but with an estimated effective capacity of 35 MW, against an estimated electric need of about 70 MW (http://www.regideso.bi/articles/78). The supply deficit is maximum during the dry season, when the country’s main hydropower plants are running at reduced capacity. The deficit in the electric power supply leads to frequent outages. A large percentage of firms in Burundi have their own back-up generator, or share access to one (https://energypedia.info/wiki/Burundi_Energy_Situation#Introduction).

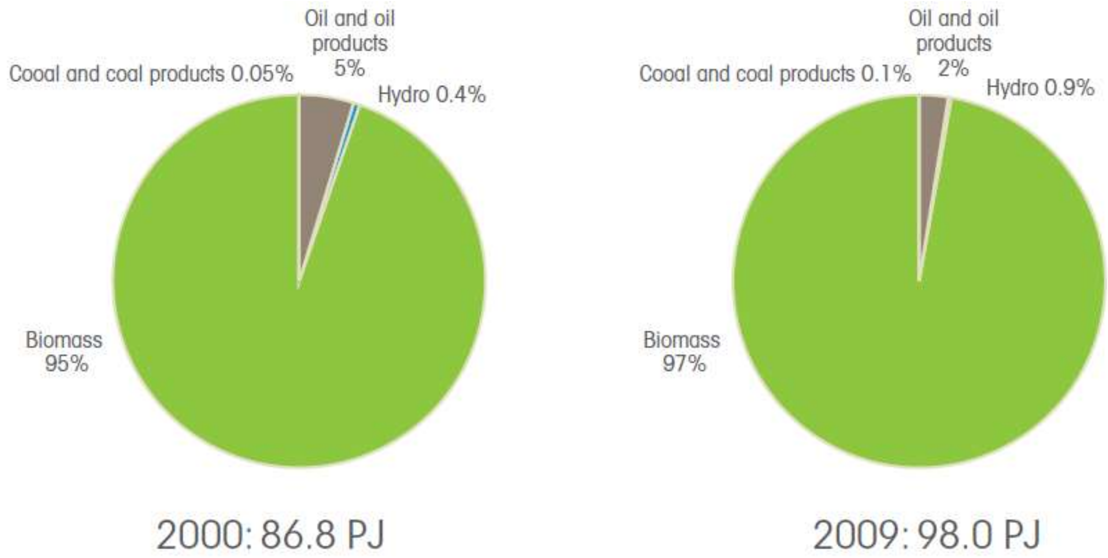
Many households in rural area use solar panels, but the overall potential of these small off-grid plants is not well known. Five national and one regional projects of Hydro are under construction with a total capacity of 121.5 MW, with addition of a Solar PV plant of 7.5 MW. These new power plants are expected to come on line after 2020 (Wakana, 2020). Total Hydro potential of Burundi is estimated at about 300 MW.

The state-controlled utility for Water and Electricity Production and Distribution (REGIDESO) is responsible for the production, distribution and marketing of water and electricity (http://regideso.bi/). The Directorate General of Hydraulics and Rural Electrification (DGHER) of the Ministry of Water, Energy and Mining (MWEM) is responsible for coordinating all activities for water supply and energy in rural areas. DGHER buys electricity from REGIDESO and distributes it to the rural customers. DGHER also operates 5 (other sources say 8) small and micro hydro plants in rural areas. The Ministry of Water, Energy and Mines (MWEM) is planning to restructure the energy sector by merging the electricity activities of DGHER with REGIDESO (https://energypedia.info/wiki/Burundi_Energy_Situation#Introduction).

It is clear that any future development of geothermal energy resources for electric power generation in Burundi shall compete with the plans to develop the consistent Hydro resources of the country and those shared with neighbour countries. Despite the willing of the Government of Burundi (GoB) to exploit also geothermal energy among the other renewables (National Development Plan 2018-2027), it is reasonable that geothermal energy is expected to cover only a limited fraction of future electric power generation in the country.

Figure 73. Map of Burundi (Source: https://www.britannica.com/place/Burundi)

Figure 74. Total Primary Energy Supply (TPES) by source for Borundi, in 2000 and 2008 (excluding electricity trade) (Source: IRENA, 2010)



The EARS is an active intra-continental rift system, comprising an axial rift with a succession of tectonic basins (rift valleys, grabens) linked by intra-continental transforms and segmented by transfer zones and accommodation zones. In Burundi the hot springs within the Rift Valley emerge from sediments with the exception of the springs at Mugara, where the water rises from Precambrian quartzites. Hot springs located outside the Rift Valley all emerge from Precambrian rocks. The hot springs in NW Burundi, e.g Ruhwa, Ruhanga and Cibitoke. do not seem to be directly associated with the Cenozoic basalts found in that area, but several researches have inferred that underplating of magma might be an important process beneath the Tanganyika Rift. The location of the hot springs identified in Burundi is shown in **Figure 75**.

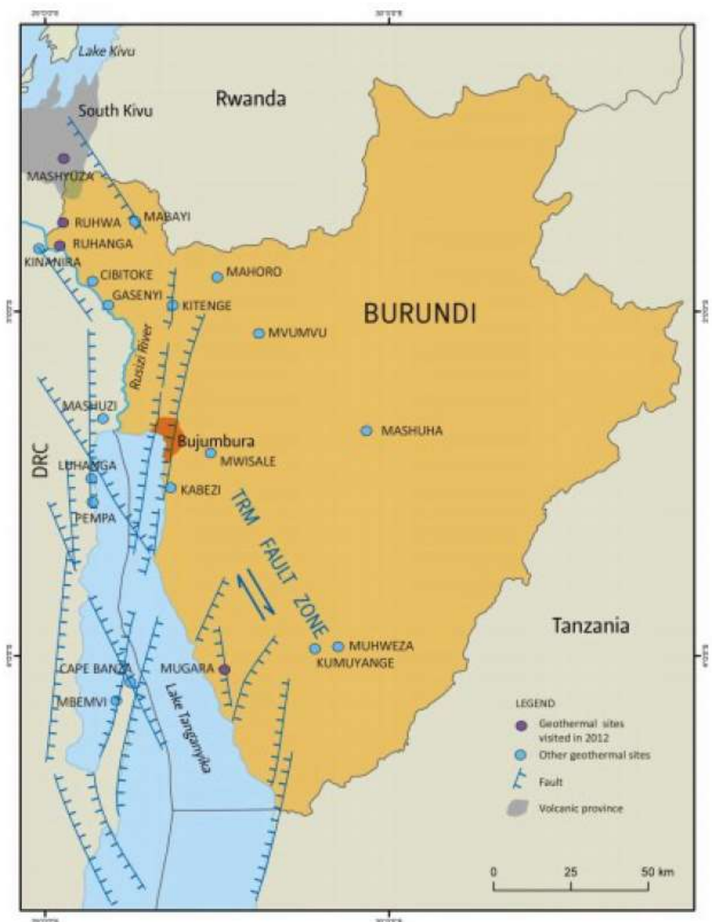
Deestra and al. (1969) made a first inventory of main hot springs in Burundi, reporting about their geo-structural context and geochemical features (Wakana, 2020). These historical studies covered in Burundi eight geothermal locations with 15 hot springs. A first geothermal reconnaissance study at the country level was conducted in 1982 following the request by the GoB to the Gov. of Iceland to evaluate the possible use of geothermal resources at the country scale. The study was conducted by ISOR and 14 areas with geothermal surface manifestations were visited (Fridriksson et al. 2012). The survey revealed that there is considerable volcanism around Lake Kivu which might be the most promising geothermal area.

In 2010, 10 known geothermal areas were visited and surveyed to gather more information on geological, structural and physico-geochemical (temperature, pH) features (Ndagije, 2016). The studied areas were located along the Rift and in the western half of the country. Surface geothermal manifestations in the form of hot spring through ancient fluvio-lacustrine terraces, around Ruhagarika, Rusizi and Ruhwa river and in Rwandan-Burundian border were mapped.

A new study was performed by ISOR under the financing of ICEIDA (Wakana, 2020). In 2013, a surface study on the Ruhwa site was carried out and the related report was validated in January 2015, under the financing of the European Development Fund under the Agreements between the European Union and EGL for the Great Lakes Regional Project.

Chemical geo-thermometers suggest the highest temperatures should be found in the Rusizi Rift Valley, where the Ruhwa spring is located (68°C). Quartz geo-thermometer application suggests an underground source temperature around 110°-120° C. All discharges arising from sediments are carbon dioxide rich, indicating the presence of a powerful heat source. In summary an exploitable geothermal source whose temperature lies in the range of 100°-160°C, may exist in the Rusizi valley and probably extends well into RDC and Rwanda (Sinzinkayo and Pasqua, 2020). This source is thought to be connected to the volcanic area south of Lake Kivu.

Figure 75. Location of major hot springs in Burundi (Source: Sinzinkayo et al., 2015)



The AGID data base lists 4 most promising geothermal sites (**Table 25**).

The AGID data bank of ARGeo reports about the national organizations which might be active on the geothermal development in Burundi, as shown in **Table 26**. MWEM, the Ministry of Water, Energy and Mining is in charge of the planning of geothermal sector development. REGIDESO and DGHER are at present responsible for the generation and distribution of electric energy.

Table 25. AGID -Burundi Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/burundi.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
Ruhagarika	Burundi			No	No	No
Mugara	Burundi			No	No	No
Kumuyange	Burundi			No	No	No
Ruhwa	Burundi			No	No	No

Table 26. AGID-Burundi Database Components: National Organizations (Source: https://agid.theargeo.org/newagid/burundi.php)

Organization	Country	Name	Status
REGIDESO	Burundi	Regie de Production et de Distribution d'Eau et del'Electricite	Active
DGHER	Burundi	Direction Generale de l'Hydraulique et de l'Electrification Rural	Active
MWEM	Burundi	Ministry of Water, Energy and Mining	Active

The reconnaissance activities performed so far confirm that geothermal resources of low and medium temperature might exist in Burundi, but the actual characteristics of those resources still need to be confirmed with surface exploration studies on most promising sites. Geothermal energy could contribute to the GoB plans to increase and diversify the sources of electric energy generation by providing a stable fraction of base load, even if reasonably expected to be limited, not affected by seasonal or meteoric changes.

3.10 Malawi

Malawi (The Republic of Malawi) is located at the extreme SW of the Western Branch of EARS along the Rift Valley (**Figure 76**). Malawi experienced a population growth from 6.2 M in 1950, to 11.1 M and 19.0 M in 2000 and 2019, respectively. The GDP rose from 1.74 B USD in 2000 to 6.96 and 7.0 B USD in 2010 and 2019, being above about 5.5 B USD since 2008. About 83% of the people live in rural areas and is still mainly employed in subsistence agriculture. The access rate to electricity increased marginally from 8% in 2009 to 12.7% in 2017 (https://www.macrotrends.net/countries/MWI/malawi/electricity-access-statistics).

The above figures are reflected in the TPES by source of generation shown in **Figure 77** with an almost unchanged situation from year 2000 to 2008 (IEA, 2010). Energy supply is dominated by Biomass (wood and charcoal) with a contribution of Oil (9-11%) which is totally imported, and Hydro (3-4%). The electricity consumption was about 85 kWh/capita in 2009, which is well below the East Africa average.

Apart from private (off grid) generators, Malawi's electricity generation was basically 99% hydro with all the generating stations cascaded on the River Shire (Gondwe et al., 2012), with the only exception of Wovwe mini-hydro power plant on River Wovwe in the Northern Region.

Malawi was facing a series of serious power shortages and interruptions due to droughts, siltation and clogging of the hydro-electric power installations by vegetation and other debris during the rainy season. This has sometimes lowered the generation to as little as 50% of the total installed hydroelectric capacity of about 304 MW. In fact, effective capacity was estimated at 286 MW and approximately 20% of it was lost as transmission and distribution losses, while the peak demand was estimated at 330 MW (Gondwe et al., 2012).

The Electricity Supply Corporation of Malawi Ltd (ESCOM) is the only supplier of commercial electricity in Malawi (http://www.escom.mw/). It has a monopoly over all generation, transmission and distribution of grid connected electricity. Most industries have opted to use their own off-grid privately-owned diesel-powered generators due to frequent black-outs (and load shedding, carried out when the power demand on the system exceeds supply) that stands at an average of about 2 months per year.

Info about the total installed capacity for electricity generation in Malawi is uncertain (Gondwe et al., 2012). According to the Department of Energy Affairs, in 2003 there was a total installed generation capacity of 355.3 MW. ESCOM is responsible for 304 MW while the remaining 51.3 MW is controlled by private investors, and used as standby during the frequent blackouts of the ESCOM supply. The other private power plant not included in the 51.3 MW is the 10 MW diesel power plant for Kayerekela Uranium Mine in Karonga. It became operational in 2007 and this brings the overall installed capacity to 365.3MW. According to Gondwe et al. (2020) the installed capacity has been increased to 555 MW adding to diesel plants of 47 and 78 MW. ESCOM is now managing an installed power of 422 MW.

It is clear that the development of geothermal energy resource for electric power generation shall compete with the consistent generation by Hydro which at present dominates the electric market in the country. On the other hand, the installed and the actually available power are not enough to supply the required power, leading to a national power deficit. As a consequence, the Government of Malawi (GoM) is considering to diversify the energy mix looking also to the possible use of geothermal resources for electric power generation considering the favourable conditions of a country crossed entirely by the Western Branch of EARS.

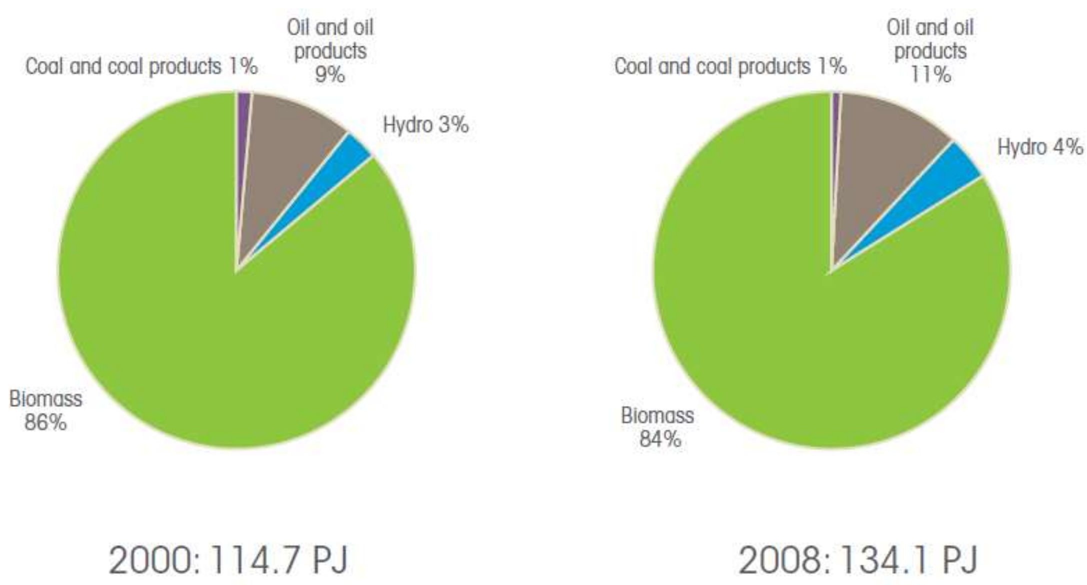
The Malawi Energy Regulatory Authority (MERA, https://mera.mw/) in its strategic plan (2009 – 2012) has highlighted the promotion of renewable energy sources. In general, it intends to increase the electricity generation in the overall energy mix from the projected 10% in 2010 to 40% in 2050 for Hydro and from the projected 5.5% in 2010 to 10% in 2050 for the other Renewable Energy Technologies. To offset the current power shortage, the GoM plans to develop a 300 MW coal-fired power plant at Ngana in Karonga District, additional 1,300 MW Hydro, and 38 MW from cogeneration plants at the two sugar companies of Dwangwa and Nchalo (Gondwe et al., 2012).

Thus, it is reasonable that geothermal energy is expected to cover only a limited fraction of future electric power generation in the country, unless the estimated 200 MW geothermal country potential will be actually confirmed by exploratory surveys and well drilling.

Geological investigations of the Malawi sector of the EARS indicate that the Malawi rift is controlled by N-S rift parallel normal faults, that also control upwards migration of the geothermal waters feeding hot springs, which occur along the length of the rift. The hot springs with possible potential for electricity generation occur mainly in the northern half of the country. They are thought to be sourced from porous sedimentary reservoirs at depth, either deeply buried young Neogene rift floor deposits or older Karoo sandstones, occurring in fault-bound basins within the Precambrian framework of the country (Gondwe et al., 2012).

Figure 76. Map of Malawi (Source: https://www.britannica.com/place/Malawi)

Figure 77. Total Primary Energy Supply (TPES) by source for Malawi, in 2000 and 2008 (excluding electricity trade) (Source: IRENA, 2010)



Within GoM sponsored activities, in 2003 the Geological Survey of Malawi reviewed hot spring resources for suitability for geothermal power. All known hot springs were recorded with a GPS and plotted on a map. Furthermore, in 2007 a study on silica and cation geothermometers was performed to determine the subsurface temperatures of thermal springs (Dulanya et al., 2007). The results predicted a highest subsurface temperature of 240°C.

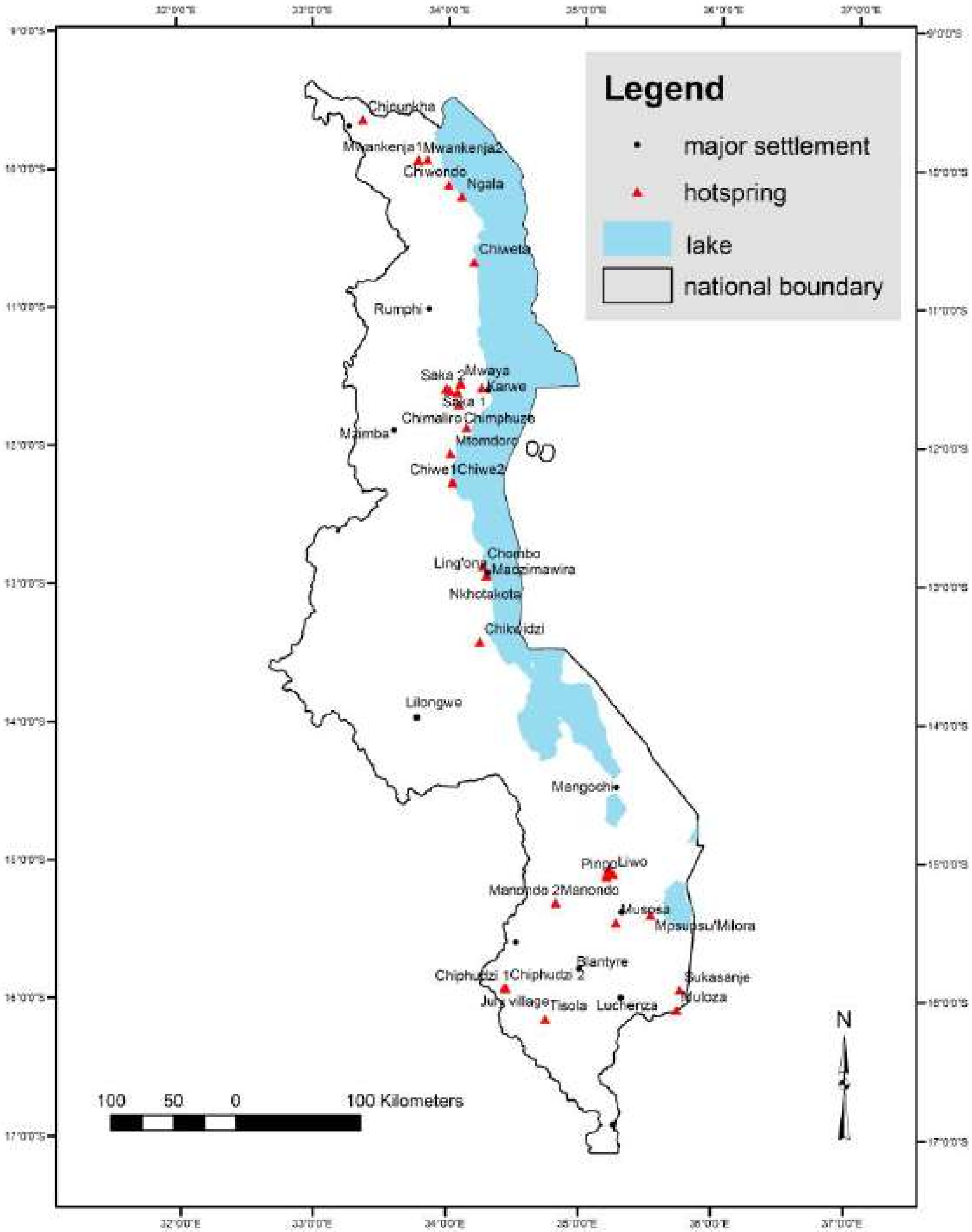
Within a recent investigation (Gondwe et al., 2012) over 55 hot springs have been visited and catalogued, 15 of which were previously undocumented. Temperatures and, where possible, flow rates and other hydrogeological parameters were measured. Samples were also collected for chemical analysis, although many of the springs were contaminated by human usage. In addition, detailed notes of their geological settings were made. The location of the surveyed hot springs is shown in **Figure 78**.

There were also private initiatives aimed at exploring the geothermal resources of Malawi. Geothermal Projects Limited and Geothermal Development Company (GDC) of Kenya in 2010 conducted a reconnaissance survey over several geothermal sites in order to identify promising prospects for exploration license application to the GoM. The GoM, acting through the Ministry of Natural Resources Energy and Mining, issued three exclusive exploration licenses to the above companies in Chiweta (Rumphi), Kasitu-Chiwe (Nkhatabay) and Mawira-Ling'ona (Nkhotakota). Licenses were revoked in 2013 due to failure to honour some of licensees' requirements. These areas are now covered in planned geothermal energy feasibility studies by the Department of Energy in the Ministry of Natural Resources, Energy and Environment.

In 2013 reconnaissance activities were performed by the Federal Institute for Geosciences (BGR) of Germany in collaboration with the Geological Survey Department (GSD) of Malawi for possible geothermal projects follow up. The same year a team from JICA, Mitsubishi Material Techno Cooperation and GSD conducted a fact-finding mission on a possible geothermal project in Malawi. This involved preliminary geothermal investigation in thermal springs of the country and various tests including in situ stream temperature, pH and conductivity of hot springs and surrounding water bodies, and brief observations on the geology of the areas surrounding the hot springs.

The Geothermal Exploration Project (GEP) carried out by ICEIDA, which later merged with the Ministry for Foreign Affairs of Iceland, with co-financing by the Nordic Development Fund (NDF), began in 2013 and finished in 2018. The project included a review of Malawi country-wide reconnaissance study and surface exploration studies which were carried out by ELC-Electroconsult for the GoM and the WB, which supported the project through the International Development Association (IDA). The project was divided into three phases.

Figure 78. Location of major hot springs in Malawi (Source: Kaonga et al., 2014)



Phase I. In this phase the focus was mainly on the reconnaissance study of all the geothermal manifestations (Eliyasi, 2018). This involved visiting all geothermal sites to get a general overview of their geological setting, collecting water as well as rock samples to get information regarding the origin of the fluids and the underground temperatures. Geological and Geochemical surveys were also done.

Geological Survey. This involved assessing the main stratigraphic, structural and hydrogeological features which were believed to have control over the formation and distribution of the geothermal system. The survey included a remote sensing study over a surface of 200 km^2 as well as geological mapping over a surface area of some 100 km^2. Rock samples were also collected for petrographic analysis.

Geochemical Survey. This involved collection of about 60 water samples from thermal and cold springs, boreholes and surface drainage. In addition to that, 18 thermal water samples were collected for the determination of dissolved gas species.

Ranking of geothermal sites. After the assessment of the geothermal sites in Phase I, they were ranked based on a set of indicators that are likely to affect the future development of these sites. The indicators were grouped into technical (temperature, flow rate, geology and chemistry) and non-technical (distance from grid, morphology, accessibility and environment) parameters. The technical and non-technical parameters were given a score based on their assumed relative importance. Those geothermal prospects with higher scores qualified into Phase II.

Phase II. In this phase, 6 prospects were selected based on rankings as described above. These were Chiweta, Kanunkha, Kasanama, Mawira, Chupudzi and Kasitu prospects. The prospects were subjected to detailed work which involved remote sensing study, geological mapping and geochemical survey. The geochemical survey involved collection of water and gases. At the end of Phase II, a new ranking was defined and two prospects were selected.

Phase III. In this phase the two selected prospects, namely Chiweta and Kasitu, were subjected to additional geoscientific investigations. These included detailed geological, geochemical and geophysical surveys, the latter focused on MT/TEM and gravimetry. Finally, the integrated based conceptual models suggested geothermal reservoirs with inferred temperature between 110° and 135° C at maximum depth of 500-750 m with electric potential of 7 and 15 MW for Chiweta and Kasitu geothermal prospects, respectively (ELC-Electroconsult, 2017b; 2017c).

The AGID data bank of ARGeo reports about the national organizations active on the geothermal development in Malawi, as shown in **Table 27**. Only MoNREE, the Ministry of Natural Resources, Energy and Environment, is reported being in charge of the planning of geothermal sector development.

Table 27. AGID -Malawi Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/malawi.php)

Organization	Country	Name	Status
MoNREE	Malawi	Ministry of Natural Resources, Energy and Environment	Active

In addition, ESCOM (http://www.escom.mw/), the National electricity utility, is in charge of geothermal energy development at the country level. The Geological Survey of Malawi (http://www.mme.gov.na/directorates/gsn/) is the technical arm of the GoM in the exploration for national geothermal resource development.

As a follow-up of the ELC-Electroconsult project, drilling of exploration slim-holes on the two most promising sites of Chiweta and Kasitu should be performed, but no definite projects exist (Gondwe et al., 2020). The reconnaissance and surface exploration activities performed so far confirm that hydrothermal geothermal resources of low and medium temperature exist in Malawi, with a possible potential for electric power generation using ORC plants. Geothermal energy could contribute to the GoM plans to diversify the sources of electric energy generation by providing a stable fraction of base load not affected by seasonal or meteoric changes, but a limited contribution from geothermal resources to the country energy requirements can be reasonably expected.

3.11 Zambia

Zambia (The Republic of Zambia) is located at the extreme SW of the Western Branch of EARS (**Figure 79**). Zambia experienced a population growth from 2.3 M in 1950, to 10.4 M and 18.3 M in 2000 and 2019, respectively. The GDP rose from the 20.27 B USD low in 2010 to 27.5 B USD in 2019, after experiencing a strong decrement in 2015 and 2016 down to about 21 B USD. About 57% of the people live in rural areas and is still employed mainly in subsistence agriculture. The access rate to electricity increased from 25% in 2009 to 40.3% in 2017 (https://www.macrotrends.net/countries/ZMB/zambia/electricity-access-statistics).

The above figures are reflected in the evolution of TPES by source of generation shown in **Figure 80**, where energy supply till 2017 is dominated by Biofuels with minor contribution from Hydro and Oil, which is totally imported. The evolution of TFC by source shown in **Figure 81** is specular to that of TPES, as electricity is generated preferentially by Hydro (83%). The electricity consumption was about 580 kWh/capita in 2010 and 730 kWh/capita in 2017, which are above the Africa average, and well above the East Africa average. Total installed electric power amounted to 2,897 MW in 2017, with a Hydroelectric generation of 12,198 GWh. The increment of electric energy consumption is driven by escalating power demand in the mining sector which accounts for about 55% of total electric energy consumption (Bwembya et al., 2018).

It is clear that the development of geothermal energy resource for electric power generation shall compete with the consistent generation by Hydro at present based on two major dams (Kariba North Bank with 1,080 MW and Kafue Gorge with 900 MW) and future planned new dams. Notably, the planned new dams include (Bwembya et al., 2018): Batoka Gorge Hydro Electric Power Scheme expected to produce 2,400 MW to be shared equally between Zambia and Zimbabwe; the Kafue Gorge Lower project which is expected to produce 750 MW; the Lusiwasi Lower, Lusiwasi Upper and Chishimba Power plants.

Low rainfall in the catchment areas in the last years has led to reduced storage in the major dams, leading to a national power deficit estimated at some 900 MW in 2016. As a consequence, the Government of Zambia (GoZ) has taken measures to mobilise both the public and private sectors to diversify the energy mix and increase both generating capacity and distribution (Vivian-Neal et al. 2016). About renewables other than Hydro, Zambia plans to develop: 50 MW from selected geothermal sites; 250 MW Solar PV under the Scaling Solar program; 200 MW Solar PV and 150 MW Wind power by ZESCO Ltd and MASEN companies, respectively.

Thus, it is clear that geothermal energy is expected to cover only a small fraction of future electric power generation from renewable resources.

Electric generation in Zambia is mostly in charge of ZESCO Limited, a vertically integrated electricity utility, which generates, transmits, distributes and supplies electricity in Zambia (http://www.zesco.co.zm/home). It is a public utility, with the GoZ being a sole shareholder.

Zambia belongs to the Western Branch of EARS which develops from Uganda throughout Lake Tanganyika, where it joins the Eastern Branch, following the border between Rwanda and the Democratic Republic of Congo. Zambia does have EARS associated geology and geothermal systems in the Northern part of the country (Chongo and Kapisya hot springs). The Western Branch is characterised with low to medium temperature geothermal systems and it is much less active in terms of volcanism, although as the Eastern Branch, it is seismically and tectonically active today.

Figure 79. Map of Zambia (Source: https://www.britannica.com/place/Zambia)

Figure 80. Total Primary Energy Supply (TPES) by source for Zambia, from 1990 to 2017 (Source: https://www.iea.org/data-and-statistics)

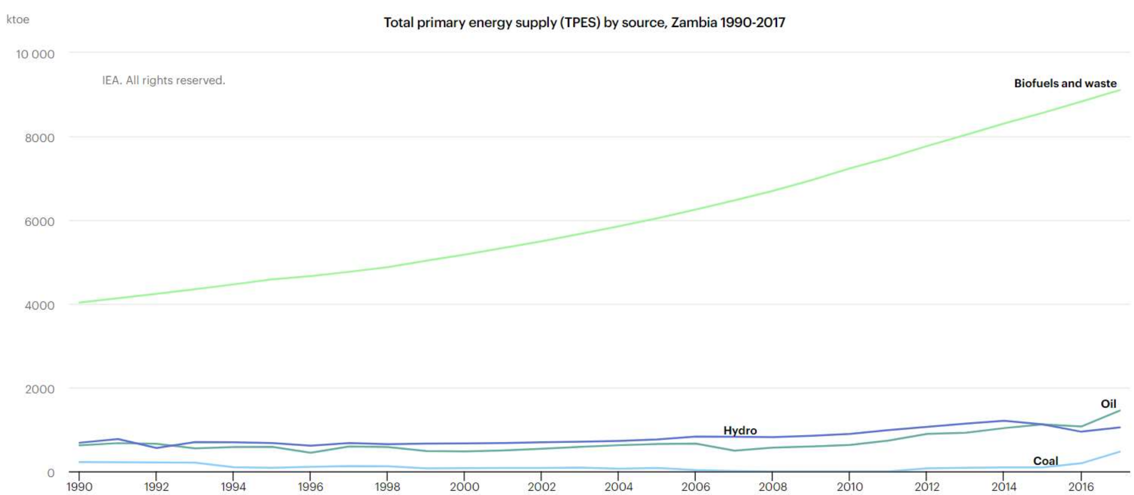
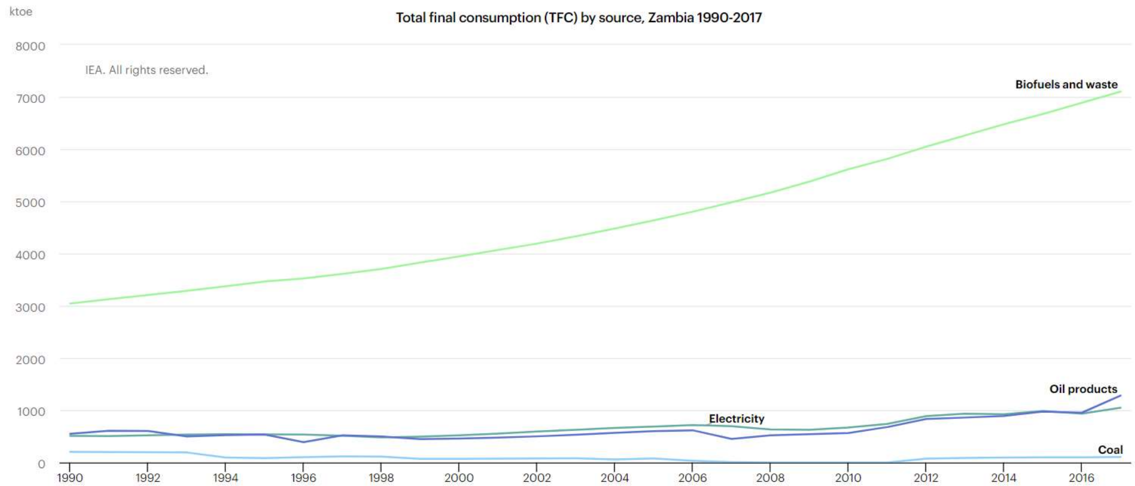


Figure 81. Total Final Consumption (TFC) by sector for Zambia, from 1990 to 2017 (Source: https://www.iea.org/data-and-statistics)



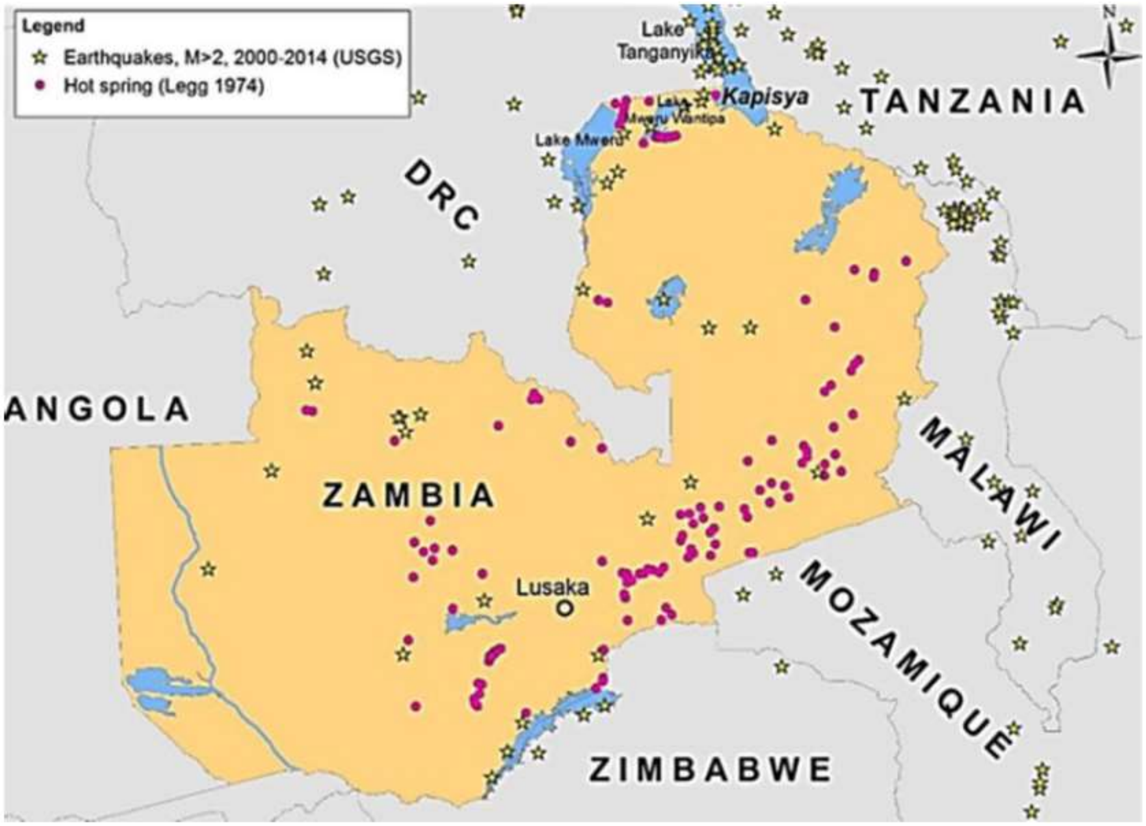
Reconnaissance surveys were carried out on geothermal targets in Zambia since the 1950s by the Geological Survey of Zambia (GSZ). Legg (1974) presents the results of a study of 50 hot or mineralised springs or groups of springs investigated between 1971 and 1974. Measurements of water temperature, discharge rate and radioactivity were made, the geological setting briefly studied, and samples of water and chemical deposits collected for analysis. More detailed investigations were made at a few springs of outstanding interest. Legg (1974) recognized that "the hot springs of Zambia occur mainly on major, probably deep, faults, often at the contacts of Karroo sediments with older rocks. The water compositions and temperatures are compatible in most cases with deep circulation by gravity, convection in fault zones, and leaching by the hot water of the soluble constituents from wall rocks". The survey identified geothermal resource areas in three different geological settings: non-volcanic Karoo (Permian) extensional basins; hot Katangan (Late Proterozoic) granites; the EARS in the North (Vivian-Neal et al. 2016).

In the 1980's a Zambian-Italian joint venture followed up earlier reconnaissance work with a drilling programme at several targets which culminated in a 200 kW geothermal pilot plant being erected at Kapisya near N'sumbu on the Lake Tanganyika Rift structure (DAL, 1987). This was designed to use a total of 15 shallow exploratory and production wells, four of which had submersible pumps installed. The plant which has two Organic Rankine Cycle (ORC) Turboden turbo-generators was designed to operate at temperature of 95°C, but it never became operational (Vivian-Neal et al. 2016).

Subsequent assessments for potential of the Kapisya (N'sumbu) and Chinyunyu geothermal prospects by KenGen in 2006 suggested on both sites a P50 potential of 2 MW (KenGen, 2007). A re-assessment by ICEIDA was rather pessimistic and suggested the Kapisya resource had limited potential for power generation (ISOR, 2014). While this has dampened the momentum for further work on the Kapisya project, both KenGen and ICEIDA recommended exploratory drilling.

With over 90 hot springs and five pre-selected sites, ZESCO's strategy at the national level is to undertake a review of the inventory of all known geothermal occurrences across the country and to establish their potential for electricity generation or other direct uses. High priority areas are the following five geothermal prospects: Chongo and Kapisya in the North, Lubungu and Mupiamanzi in the West, Chinyunyu in the East. A description of main characteristics of the 5 geothermal sites is given by Bwembya et al. (2018).

Figure 82. Location of hot springs in Zambia and earthquakes with M>2 occurred in 2000-2014 (Source: Agnelli, 2020)



Kalahari GeoEnergy Ltd (https://kalaharigeoenergy.com/), a private developer, performed advanced exploration surveys in Bweengwa River which lies within the Kafue Trough, in Lochinvar, in the southern part of Zambia. The Bweengwa River Geothermal Resource Area covers the southern part of Lochinvar National Park and lands sparsely occupied by pastoralist people to the south of the Park. The Bweengwa River Geothermal Resource is the only Zambian site included in the AGID data base (**Table 28**).

Table 28. AGID -Zambia Database Components: Sites. Power in MW. (Source: http://agid.theargeo.org/newagid/zambia.php)

Name	Country	Potential Power	Exisiting Power	Reconn.	Surf.	Drill.
Bwengwa River geothermal resource	Zambia	0	0		Y	Y

Exploration work undertaken up to 2017 include (Bwembya et al., 2018) (https://kalaharigeoenergy.com/exploration-resource/):

- Geological mapping.
- Hydrochemistry sampling.
- Geophysics (including ground magnetics, AMT resistivity, radiometric, gravity, combined 3D modelling, and LiDAR/Thermal IR).
- Shallow soil temperature measurements.

- Well design, drilling and logging of fourteen (14) temperature gradient holes, total 3,500 m.
- Planning of deep (1,100 m) slim well drilling.

Exploration proceeded in 2018-2019 with a program including LiDAR, Color Orthoimagery and Thermal Infrared Imagery (TIR) surveys, structural mapping and drilling of 8 shallow temperature gradient holes (TGH) to 150 m depth that have been used to update the conceptual model to support targeting of slim holes to confirm a reservoir up-flow inferred at 130 to 150°C (Hinz et al., 2020). The exploration program included also geologic mapping, analysis of fluid geochemistry, geophysical surveys (AMT, gravity, magnetics), developing conceptual models, drilling six slim hole wells to 250-550m depth, and analysing core and cuttings to update conceptual models. The six slim holes were located 0.6 to 1.5 km NW of the Southern Bounding fault and reached a maximum temperature of 102 °C.

The surface manifestations of the Bweengwa River Geothermal Resource Area include geothermal springs that extend over 9 km and lie on the southern basin bounding regional fault of the Kafue Trough. Results confirm a geologic setting conducive for geothermal hydrothermal systems and give a strong probability of a medium-low enthalpy geothermal resource with temperatures up to 150°C that can support a power generation project of at least 10 MW based on ORC plants. Heat-in-place, power density and heat flow methods were used for the evaluation of resource potential, providing a consistent estimated usable resource capacity in the range of 6-16 MW (P90 – P50).

The Bweengwa River Geothermal Resource Area contains compelling evidence of the three key elements required for hosting a hydrothermal system: temperature, permeability and water recharge. Evidence for minimum reservoir temperature from 130°C to more than 150°C is provided by both fluid chemistry and temperature gradient holes (104°C recorded in LOCH-02 and LOCH-05 at 440 and 564 m depth, respectively). Permeability is confirmed by the discharge of the hot springs along the regional bounding fault and the associated geologic structures. The reservoir is in fractured basement rocks at a shallow to medium depth adjacent to the bounding fault. The source of water is local meteoric water whose recharge is assured.

The resource capacity is planned to be verified with drilling programme of 3 slim holes targeted to encounter at least 130°C geothermal fluids near the top of the reservoir. If the wells and subsequent testing are successful, the results will be used in a feasibility study that should supply the basis for the field development with the final target to build a 15 MW power plant. On April 24, 2020, Kalahari GeoEnergy has secured a convertible loan of 3.2 M USD from the Renewable Energy Performance Platform (REPP, https://repp.energy/) to drill 3 slim-holes in the Bweengwa River prospect.

The Kafue Trough is believed to have good prospecting characteristics for additional geothermal resources similar to Bweengwa River. Kalahari GeoEnergy Ltd considers realistic that ongoing exploration may significantly increase the current estimated resource capacity. The most prospective area is the Longola springs, which are evident along a strike length of 3.25 km in a similar position along the northern margin of the Kafue Trough and are essentially a mirror image of the Bweengwa River springs (Vivian-Neal et al. 2016).

The AGID data bank of ARGeo reports about the national organizations active on the geothermal development in Zambia, as shown in **Table 29**. Only MoE, the Ministry of Energy, is reported which is in charge of the planning of geothermal sector development. ZESCO Limited (https://www.zesco.co.zm/), the National electricity utility, is in charge of geothermal energy development at the country level. Kalahari GeoEnergy Ltd is the only private developer at present active in Zambia.

Table 29. AGID -Zambia Database Components: National Organizations (Source: http://agid.theargeo.org/newagid/zambia.php)

Organization	Country	Name	Status
MoE	Zambia	Minister of Energy	Active

The reconnaissance and exploration activities performed so far confirm that hydrothermal geothermal resources of low and medium temperature exist in Zambia, mainly linked to fractured bed rocks and fault-controlled systems. Potential for some 50 MW to be generated using ORC plant is inferred. Despite the GoZ need and willing to diversify the sources of electric energy generation, it seems that even in the most optimistic case geothermal energy will be able to supply only a very small fraction (<1.5%) of electric power planned from renewable sources.

4 Conclusions

A review of the status of geothermal industry in 10 East African countries crossed by the EARS (East African Rift System), plus the Comoros, has been conducted in the framework of the project ACEWATER2 ("*The African Networks of Centres of Excellence on Water Sciences PHASE II*") implemented by JRC in partnership with UNESCO. The review has been based on public available documents and news and was focused on geothermal resource development for electric power generation. The peculiar characteristics of geothermal energy and the obstacles to their wider use has been analyzed in the contest of the conditions found in East Africa.

The East African Rift System (EARS) is formed by the Eastern Branch, which develops from the Afar Depression to the northern volcanic province in Tanzania, crossing Eritrea, Djibouti, Ethiopia and Kenya, and by the Western Branch which crosses Uganda, Burundi, Rwanda, Tanzania and Malawi reaching Zambia with its SW extension. The Eastern Branch is characterized by a much widespread quaternary volcanic activity, with large calderas and volcanic centres along the rift axis, with the presence of shallow magma bodies. Geothermal prospects are mainly consisting in volcanic hosted high temperature geothermal systems. The Western Branch, on the other hand, has limited volcanic centres, with the absence of shallow magmatic bodies and is characterized by geothermal prospects mainly associated to medium, rarely high, temperature fault controlled hydrothermal systems. As a consequence, about 95% of EARS estimated potential amounting to some 22,430 MW belongs to geothermal areas located along the Eastern Branch.

Despite the huge EARS estimated geothermal potential, until now only Kenya was able to develop a fraction of its resources by installing 865 MW by the end of 2019. The reasons for such a delay after decades of surface exploration are known, being related to: the high costs of exploration drilling with associated mining risks which are difficult to be accepted by financing institutions; the lack of professionals and expertise necessary for project planning, execution and management; the lack of a coherent legislative and regulation framework for geothermal operations; the competition with other renewables, such as solar PV and hydro, not affected by mining risks and characterized by lower LCOE. Both national governments and international stakeholders are actively working to overcome the above obstacles.

The 5 countries crossed by the Eastern Branch of EARS, namely Eritrea, Djibouti, Ethiopia, Kenya and Tanzania, account for approximately 21,35 of which some 20,000 MW are inferred to be located in Ethiopia and Kenya.

Eritrea has basically a single explored site, Alid volcanic complex, with reported potential of 70-100 MW. Despite the acquired knowledge is still insufficient to target exploration wells, further activities aimed at completing the surface exploration and target exploratory drillings seem worth to be performed, as the installation of a 50 MW geothermal plant in Eritrea would already cover most of its national base load.

Surface and drilling exploration in **Djibouti** dates back to late ‘70s, with several prospects recently explored with surface surveys and new exploratory wells drilled in 2 prospects within the Asal rift area at Gale le Koma and Fialé caldera. The latter found high temperatures and apparently limited well deliverability, subject to confirmation by a well testing program. In Djibouti too the installation of a geothermal power plant of some 50 MW would cover most if its electric network base load, consistently reducing the use of imported oil. ODDEG is the public institute in charge of surface exploration and field development which is managing all the initiatives under way focusing all the national efforts and international contributions.

Ethiopia has a large inferred potential in the order of 10,000 MW, but despite exploration activities started in the '70s and exploration drilling performed since mid '80s, only a 7.5 MW power plant was installed at Aluto caldera, now not in operations. Licenses assigned to private operators since 2009 have led only to surface exploration activities, with the performance of more expensive exploratory drillings hindered by a not clear regulation framework. The situation has recently changed thanks to a new geothermal proclamation and regulations issued in 2016 and 2019, respectively. This facilitated the signing of new PPA and IA for the Tulu Moye and Corbetti caldera in march 2020, with drilling activities started in Tulu Moye. Other operators, most of which have obtained grants from the GRMF for both surface surveys and exploratory drillings, will likely to proceed on the other 6 already licensed prospects. EPP, the public electric utility in Ethiopia, is the operator for the Aluto Langano field development project aimed at providing the steam for a new power plant. Within the same project, funded by the World Bank, EEP is purchasing 2 complete drilling rigs which are planned to be used for future drilling exploration activities after the completion of Aluto field development. Geothermal development in Ethiopia will face the competition with cheaper renewables, such as the huge hydropower resources presently developed by EEP and the large estimated solar and wind resources.

Kenya is the leading country as far as the geothermal development in East Africa. It's a success story characterized by the development of the great Olkaria geothermal field by a public electric utility, KenGen, now able to explore, drill and operate the field and the power plants with its own personnel, equipment and facilities. GDC has been entrusted by the Gov. of Kenya of the development of national resources by performing surface surveys and prospect development to eventually select IPP for the construction and operation of the power plants. Following this approach, GDC is going to complete the development of Menengai field with 3x35 MW power plants, while is actively exploring other interesting prospects. Opening to private operators and to PPP models, allowed a faster development of the Great Olkaria field where the private operator OrPower 4 is already approved PPP projects for ready generating 155 MW. Other operators are actively exploring other prospects along the Rift Valley, with more than 2,000 MW planned. Kenyan experience is taken as a successful example of geothermal industry, with both KenGen and GDC providing consultancies and services to neighbouring countries. Kenya has been also chosen as the location of the Africa geothermal Centre of Excellence operated by GDC in collaboration with KenGen.

Tanzania has deployed several efforts in last years both with the creation in 2011 of TGDC, the state-owned company with the main mission to develop the national geothermal sector, as well as on the exploration of the most promising prospects. Despite these efforts, fuelled by large inferred potential estimates of some 5,000 MW, results so far acquired on 3 out of 4 flagship prospects indicate mostly low to medium temperature reservoirs of limited potential which can be exploited using ORC plants. These results obtained in prospects located on the Western Branch of EARS, in some way similar to those obtained in other countries crossed by the Western Branch, are linked to the different geological and vulcanological features which allows the evolution of medium temperature fault controlled geothermal systems rather than volcanic hosted high temperature systems preferentially found in the Eastern Branch. The potential has been recently conservatively estimated in 500 MW. When compared to the planned electric power development in Tanzania, it is clear that geothermal energy will play a minor role in the future energy mix, unless additional exploration activities will identify new promising prospects.

Comoros are a small archipelago of volcanic islands located between Mozambique and Madagascar in the Indian Ocean. Surface exploration of the Karthala prospect in Grande Mayotte allowed to identify a geothermal potential of up to 40 MW, largely exceeding the base load of the country Exploration wells have been targeted and a project is underway with the aim to drill 3 exploration wells.

6 countries are crossed by the Western Branch of EARS, namely Uganda, Rwanda, Burundi, Tanzania, Malawi and Zambia. Their cumulative estimated potential amount to some 1,040 MW.

Uganda is crossed by the Western Branch along its western border. The 4 most promising prospects have been studied with detailed surface exploration surveys and drilling of gradient wells, namely Katwe-Kikorongo, Buranga, Kibiro and Panyimur. Results achieved suggest medium temperature fault-controlled reservoirs with temperatures in the range 110 – 150°C, with possible upper temperature of 200°C for the Buranga prospect only. No prospect is ready for deep exploratory drilling. Despite the evaluation of Uganda geothermal potential at 450 MW, at present the availability of geothermal resources suitable for power generation are still to be confirmed. A limited contribution from geothermal resources to the country electric power requirements can be reasonably expected in the future.

Rwanda is crossed on its western part by the Rift Valley. Despite its position, the geothermal potential of Rwanda has been recently revised to only 90 MW. Exploration activities have been conducted on the 4 most promising prospects, namely Karisimbi, Kinigi, Gisenyi and Bugarama. 3 of them resulted not to host geothermal systems suitable for power generation. Higher temperatures up to about 160-200°C have been inferred for a deep reservoir in Giseny, but additional surface exploration is necessary before moving to a deep exploration drilling phase. Despite the willing of the Government of Rwanda to diversify the sources of electric energy generation by developing also geothermal resources, results achieved so far indicate that the known geothermal sites in the country have an overall limited potential and will not be able to give a remarkable contribution to the future electric energy generation in Rwanda.

Burundi is crossed NS by the Rift Valley. Geochemical surveys suggest the highest temperatures should be found in the Rusizi Valley, with an inferred geothermal resource with temperature in the range of 100°-160°C. The reconnaissance activities performed so far confirm that hydrothermal geothermal resources of low and medium temperature might exist in Burundi, but their characteristics still need to be confirmed. Geothermal energy could contribute to the Government of Burundi plans to increase and diversify the sources of electric energy generation by providing a stable fraction of base load, but those resources are reasonably expected to be limited.

Malawi is located along the Rift Valley. The reconnaissance and surface exploration activities performed so far confirm that hydrothermal geothermal resources of low and medium temperature exist in Malawi. A Geothermal Exploration Project encompassing the whole country completed in 2018 identified Chiweta and Kasitu as the most promising prospects with inferred temperature between 110° and 135°C, at the lower temperature range for electric power generation with ORC plants, with an estimated potential of some 10 MW each. According to the results of the project, a limited contribution from geothermal resources to the country energy requirements can be reasonably expected.

Zambia is crossed by a SW extension of the Western Branch of EARS. ZESCO, the public utility in charge of geothermal development, has identified five priority prospects on which detailed surface studies need to be completed, namely Chongo and Kapisya in the North, Lubungu and Mupiamanzi in the West, Chinyunyu in the East. Advanced surface exploration surveys have been performed by Kalahari GeoEnergy at Bweengwa River prospect in southern Zambia. Results confirm the existence of a fault-controlled geothermal system with temperatures up to 150°C that can support a power generation project of at least 10 MW based on ORC plants. The activities performed so far confirm that hydrothermal geothermal resources of low and medium temperature exist in Zambia, mainly linked to fractured bed rocks and fault-controlled systems. A total potential for some 50 MW to be generated using ORC plant is inferred. Despite the Government of Zambia need and willing to diversify the sources of electric energy generation, it seems that even in the most optimistic case geothermal energy will be able to supply only a very small fraction of electric power planned from renewable sources.

In conclusion, thanks to the efforts of both national governments and international stakeholders, the geothermal energy in Eastern Branch countries of EARS seems to be at a turning point in particular in Ethiopia and Djibouti, with Kenya going on in an accelerated way along an already established successful path. Geothermal exploration in the Comoros has also good perspectives with geothermal potential to be confirmed, but largely exceeding the present base load of the country.

The situation is different for the geothermal areas located on the Western Branch characterized by low to medium temperature fault-controlled systems of limited power generation capacity. Updated exploration approaches tailored for fault-controlled system have recently improved the understanding of the studied systems and might be effective in locating additional promising prospects. So far, only a couple of prospects in Zambia and Tanzania have been successfully explored at a stage suitable for targeting deep exploration wells. Geothermal energy seems not to be able to supply a remarkable contribution to power generation needs of the country crossed by the Western Branch of the EARS.

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List of abbreviations and definitions

AAU	Addis Ababa University
AFESD	Arab Fund for Economic and Social Development
AFD	Agence Française de Dévelopment
AfDB	African Development Bank
AGCE	Africa Geothermal Center of Excellence
AGF	Africa Geothermal Facility (New Zealand)
AGID	Africa Geothermal Inventory Database
ARGeo	African Rift Geothermal (Facility)
AU	African Union
AUC	African Union Commission
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (German Federal Institute for Geosciences and Natural Resources)
CERD	Djibouti Center for Studies and Research
CIF	Climate Investment Funds
CIP	Climate Investment Platform
CFE	Comisión Federal de Electricidad
CoE	Centre of Excellence
CTF	Clean Technology Fund
DGHER	Directorate General of Hydraulics and Rural Electrification
EAGER	East Africa Geothermal Energy Facility
EAPL	East African Power and Lighting Company Ltd.
EARS	East African Rift System
EDC	Energy Development Corporation
EDD	Electricité de Djibouti
E&P	Exploration & Production
EEA	Ethiopian Energy Authority
EEP	Ethiopian Electric Power
EGEC	European Geothermal Energy Council
EGC	European Geothermal Congress
EGS	Enhanced Geothermal Systems
EIB	European Investment Bank
EIWR	Ethiopian Institute of Water Resources, Addis Ababa University
EPC	Engineering Procurement & Construction
ESCOM	Electricity Supply Corporation of Malawi (Ltd)
ESIA	Environmental and Social Impact Assessment
ESMAP	Energy Sector Management Assistance Program
ETIP-DG	European Technology & Innovation Platform on Deep Geothermal
EU	European Union

EU ITF	EU-Africa Infrastructure Trust Fund
EWSA	Energy, Water and Sanitation Authority (Rwanda)
FCRS	Fluid Collection and Reinjection System
FIT	Feed-in-Tariffs
FY	Fiscal Year
GDC	Geothermal Development Company (of Kenya)
GDP	Gross Domestic Product
GEA	Geothermal Energy Association
GEF	Global Environment Facility
GEP	Geothermal Exploration Project
GERD	Great Ethiopian Renaissance Dam
GGA	Global Geothermal Alliance
GGDP	Global Geothermal Development Plan.
GHG	GreenHouse Gas
GIS	Geographical Information System
GoB	Government of Burundi
GoD	Government of Djibouti
GoE	Government of Ethiopia
GoK	Government of Kenya
GoM	Government of Malawi
GoR	Government of Rwanda
GoT	Government of Tanzania
GoU	Government of Uganda
GoZ	Government of Zambia
GRC	Geothermal Resources Council
GRMF	Geothermal Risk Mitigation Facility (for Eastern Africa)
GSE	Geological Survey of Ethiopia & Geological Survey of Eritrea
GSDP	Geothermal Sector Development Project
GST	Geothermal Service of Tanzania
GSZ	Geological Survey of Zambia
GTP	Geothermal Training Program
IA	Implementation Agreement
IAEA	International Atomic Energy Agency
IBRD	International Bank for Reconstruction and Development
ICE	Instituto Costarricense de Electricidad
ICEIDA	ICElandic International Development Agency
ICSID	International Centre for Settlement of Investment Disputes
IDA	International Development Association

IEA	International Energy Authority
IFC	International Finance Corporation
IGA	International Geothermal Association
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
ISOR	Iceland GeoSurvey
JICA	Japan International Cooperation Agency
JRC	Joint Research Centre
JV	Joint Venture
KenGen	Kenya Electricity Generating Company
KETRACO	Kenya Electricity Transmission Company
KFAED	Kuwait Fund for Arab Economic Development
KfW	Kreditanstalt für Wiederaufbau (Credit Institute for Reconstruction)
KPLC	Kenya Power and Lighting Company
LCOE	Levelised Cost Of Electricity
MER	Main Ethiopian Rift
MERA	Malawi Energy Regulatory Authority
MFA	Ministry of Foreign Affairs
MIGA	Multilateral Investment Guarantee Agency
MT	Magneto Telluric
NCG	Non-Condensable Gas
NDC	Nationally Determined Contribution
NDF	Nordic Development Fund
NZ	New Zealand
OAU	Organisation of African Unity
OECD	Organization for Economic Co-operation and Development
ODA	(Japan's) Official Development Assistance
ODDEG	Office Djiboutien de Developpement de l'Energie Geothermique (Djibouti Office for Geothermal Energy Development)
O&G	Oil and Gas
O&M	Operation and Maintenance
OPEC	Organization of Petroleum Exporting Countries
ORC	Organic Rankine Cycle
P	Pressure
P&T	Pressure and Temperature
PGE	Pertamina Geothermal Energy
PISSA	Project Implementation and Steam Supply Agreement
PLN	Perusahaan Listrik Negara (Indonesian State Electricity Company)

PPA	Power Purchase Agreement Public Private Partnerships
PPP	Public-Private-Partnerships
PSIF	Private Sector Investment Finance
PV	PhotoVoltaic
RD&I	Research Development & Innovation
R&D	Research & Development
RD&D	Research, Design & Development
REGIDESO	Directorate for Production and Distribution of Water and Electricity
REPP	Renewable Energy Performance Platform
RG	Reykjavik Geothermal
RGP	Regional Geothermal Program
RMCs	Regional Member Countries
SME	Small and Medium Enterprises
SREP	Scaling-up Renewable Energy Program
SDGs	Sustainable Development Goals
T	Temperature
TANESCO	Tanzania Electric Supply Company Limited
TDEM	Time-Domain ElectroMagnetic
TDS	Total Dissolved Solids
TEM	Transient ElectroMagnetics
TFC	Total Final Consumption
TGDC	Tanzania Geothermal Development Company
TGH	Temperature Gradient Hole
TIR	Thermal Infrared Imagery
TMGO	Tulu Moye Geothermal Operations
ToR	Terms of Reference
TPES	Total Primary Energy Supply
UN	United Nations
UNDP	United Nations Development Program
UNECE	United Nations Economic Commission for Europe
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFC	United Nations Framework Classification for Resources
UNU	United Nations University
US-ACEF	United States-Africa Clean Energy Finance
USAID	United States Agency for International Development
USEA	United States Energy Association
US-EAGP	United States -East Africa Geothermal Partnership
USGS	United States Geological Survey

USTDA	United States Trade and Development Agency
WACC	Real Weighted Average Cost of Capital
WB	World Bank
WBG	World Bank Group
WEFE	Water-Energy-Food-Ecosystem
WGC	World Geothermal Congress
WWW	World Wide Web
XRD	X-Ray Diffraction
XRF	X-ray Fluorescence
ZAMCOM	ZAMbezi water course COMmission

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