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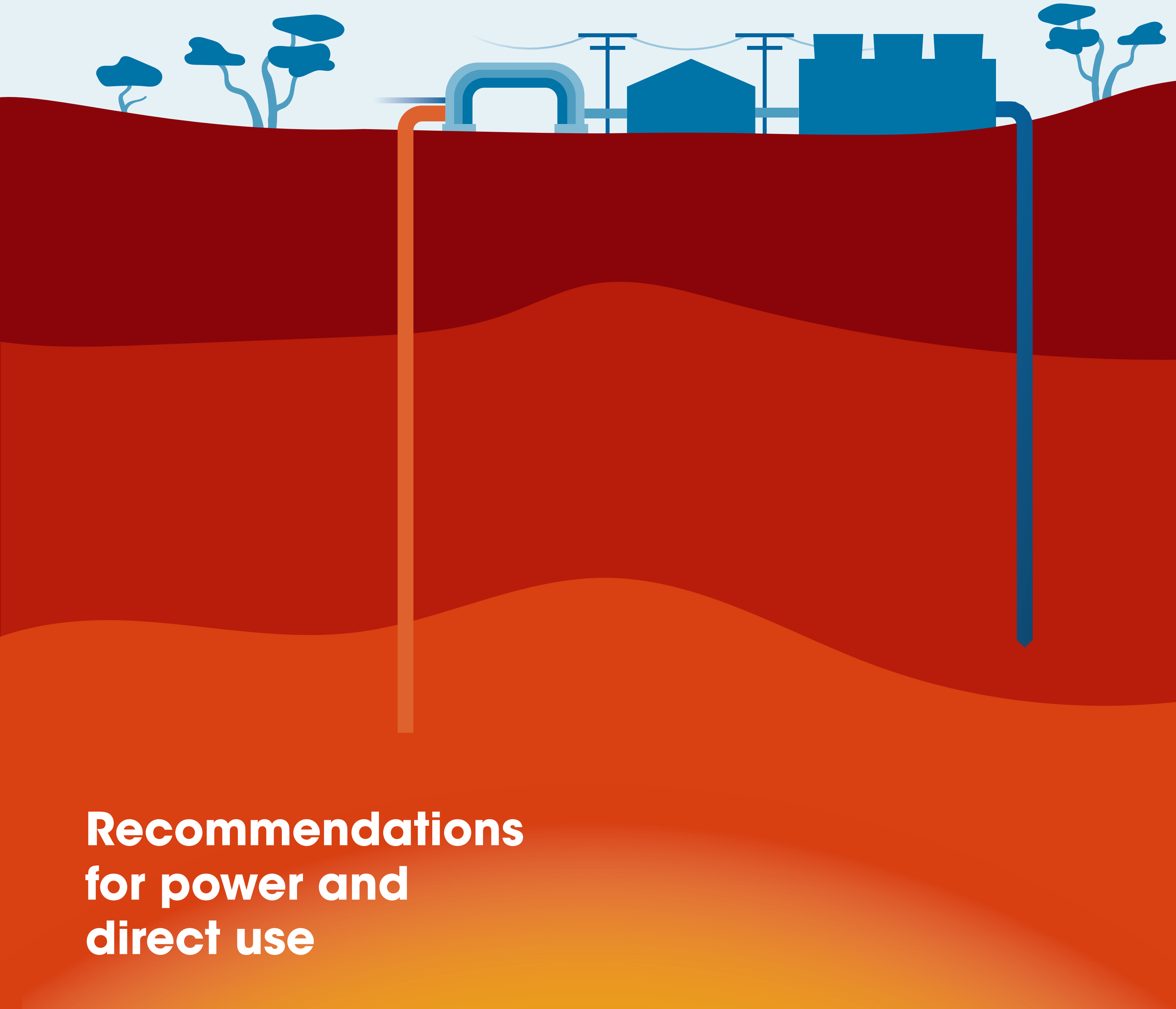
International Renewable Energy Agency

GEOTHERMAL DEVELOPMENT IN EASTERN AFRICA



Recommendations for power and direct use

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Citation: IRENA (2020), *Geothermal Development in Eastern Africa: Recommendations for power and direct use*, International Renewable Energy Agency, Abu Dhabi.

ISBN 978-92-9260-268-0

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ACKNOWLEDGEMENTS

IRENA is grateful for the valuable contributions of the energy experts and other relevant stakeholders in the preparation of this study. This includes all the participants involved in a survey carried out in July and August 2019 and in the online consultation meeting held on 28 October 2019.

The report was reviewed by several experts, including Godfrey Bahati, Vincent Kato (Ministry of Energy and Mineral Development - Uganda), Mike Allen (New Zealand), Hans Jaoko (USAID), Jon Jonsson (Reykjavik Geothermal), Antony Karembu (African Development Bank - AfDB), Crispin Lupe (Ministry of Energy - Kenya), Peketsa Mangi (Kenya Electricity Generating Company - Kenya), Chaheire Mohamed (Comoros), Kayad Moussa (ODDEG - Djibouti), Silvain Ngaryo (African Union Commission), Cornel Ofwona (Geothermal Development Company - Kenya), Andrew Palmateer (United States Energy Association), Julian Richardson (Parhelion), Eiji Wakamatsu (Japan International Cooperation Agency - JICA), Meseret Zemedkun (UNEP) and Jacques Varet (SARL Geo2D). Valuable input and feedback were provided by the following IRENA colleagues: Fabian Barrera, Nopenyo Dabla, Albertine Devillers, Annah Jabesh, Paul Komor, Yunshu Li, Asami Miketa, Paula Nardone, Carlos Ruiz, Jef Vincent, Elizabeth Wanjiru, Adrian Whiteman and Benson Zeyi.

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IRENA is grateful for the support provided by the government of Japan in producing this publication.

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ABBREVIATIONS

ACEC	Africa Clean Energy Corridor Initiative
AFD	French Development Agency (Agence Française de Développement)
AFREC	Africa Energy Commission
AGAP	Afar Geothermal Alternative Power Share Company (Ethiopia)
AGCE	Africa Geothermal Centre of Excellence
ARGeo	Africa Rift Geothermal Development Facility
AUC	African Union Commission
AfDB	African Development Bank
BGR	Federal Institute for Geosciences and Natural Resources of Germany (Bundesanstalt für Geowissenschaften und Rohstoffe)
CAPP	Central African Power Pool
CHP	Combined heat and power
CP	Conditions precedent
CTCN	Climate Technology Centre and Network
CTF	Clean Technology Fund
CTN	Climate Technology Network
EAGER	East Africa Geothermal Energy Facility
EAPP	Eastern Africa Power Pool
EARS	East African Rift System
EEP	Ethiopian Electric Power
ESMAP	Energy Sector Management Assistance Programme
FAO	Food and Agriculture Organization (UN)
FIT	Feed-in tariff
GDC	Geothermal Development Company (Kenya)
GEF	Global Environment Facility
GIZ	German International Corporation Agency
GRMF	Geothermal Risk Mitigation Facility
GRO-GTP	Centre for Capacity Development, Sustainability and Societal Change in Iceland Geothermal Training Programme
GSE	Geological Survey of Ethiopia
ICEIDA	Icelandic International Development Agency
IGA	International Geothermal Association
IGA-ARB	International Geothermal Association-Africa Regional Branch
INVESTA	Investing in Sustainable Energy Technologies for the Agri-food sector

IRENA	International Renewable Energy Agency
Iceland-MFA	Iceland Ministry of Foreign Affairs
JICA	Japan International Cooperation Agency
KenGen	Kenya Electricity Generating Company PLC
KfW	German Development Bank (Kreditanstalt für Wiederaufbau)
LCOE	Levelised cost of electricity
MEQ	Micro earthquake
MER	Main Ethiopian Rift
MT	Magnetotelluric
NDC	Nationally determined contribution
NDF	Nordic Development Fund
NZ-AGF	New Zealand Africa Geothermal Facility
ODDEG	Djiboutian Office of Geothermal Energy Development (Office Djiboutien de Développement de l'Energie Géothermique) (Djibouti)
ORC	Organic Rankine Cycle
P4G	Partnering for Green Growth and Global Goals 2030 (Denmark)
PISSA	Project Implementation Steam Sales Agreement
PPA	Power purchase agreement
RAMP	Risk Assessment and Mitigation Platform (IRENA)
RGCU	Regional Geothermal Coordination Unit
SAPP	Southern Africa Power Pool
SDG	Sustainable Development Goals
SEFA	Sustainable Energy Fund for Africa
SREP	Scaling up Renewable Energy Program
TEM	Transient electromagnetics
TGDC	Tanzania Geothermal Development Company
TGH	Thermal gradient hole
TMGO	Tulu Moye Geothermal Operations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFC	United Nations Framework Classification for Resources
UNStats	United Nations Statistics Division
UNU-GTP	United Nations University Geothermal Training Programme
USAID	United States Agency for International Development

EXECUTIVE SUMMARY

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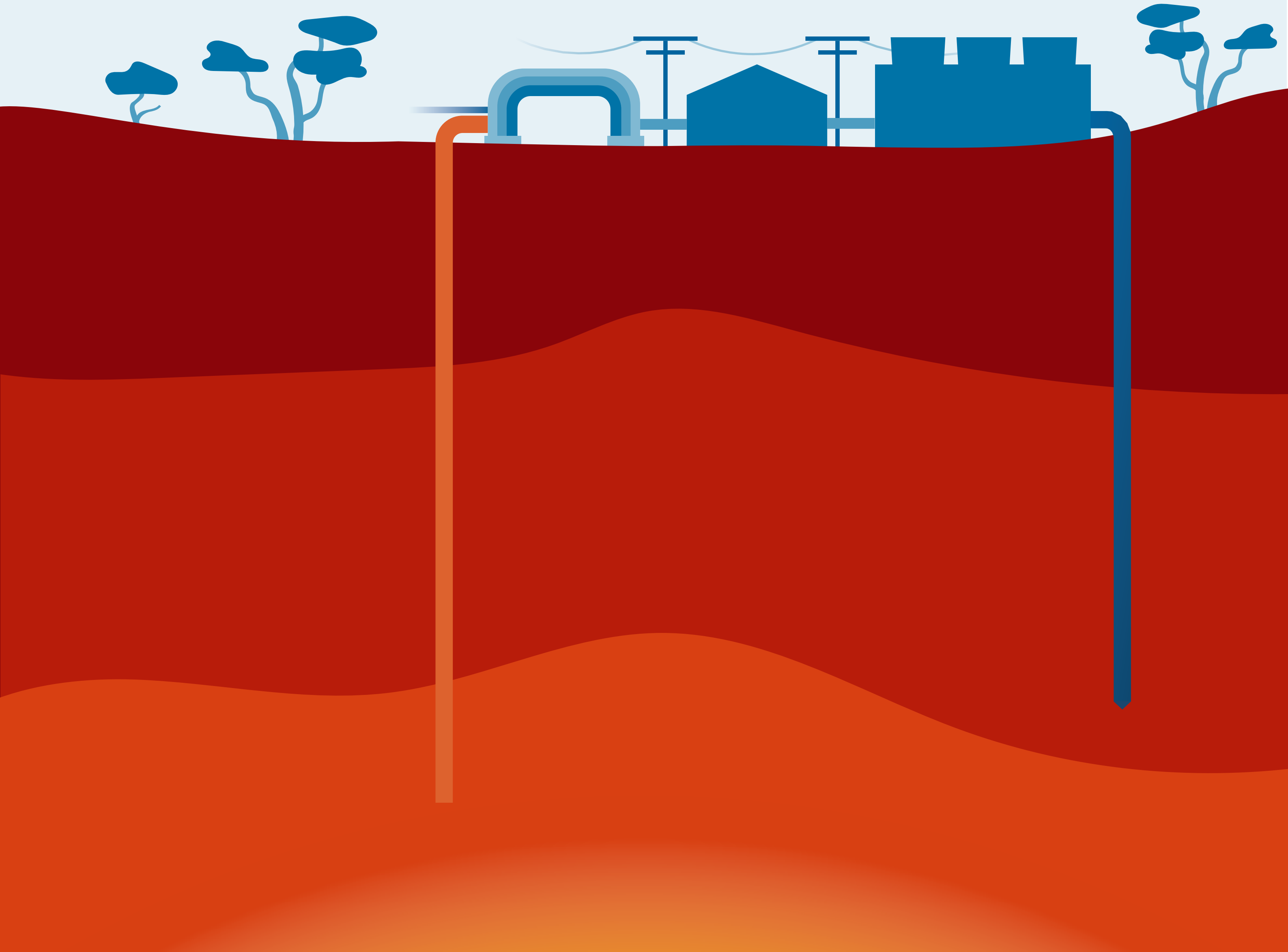
The countries of the East African Rift region are endowed with significant geothermal potential for electricity production, as well as for direct use. Harnessing these resources can provide a renewable, affordable and stable energy supply. It can also help governments meet the objectives of the 2030 Agenda for Sustainable Development and the climate objectives set out by the Paris Agreement.

Nevertheless, only about 900 megawatts-electrical (MWe) of installed geothermal electricity capacity exists in the region to date, via power plants in Ethiopia and Kenya. Yet geothermal resources have been confirmed via drilling of deep exploration wells in Djibouti and shallow wells in the Democratic Republic of Congo (DRC) and Zambia. As of May 2020, however, active drilling of geothermal wells was taking place only in Djibouti, Ethiopia and Kenya, with other regional countries only at the surface exploration phase of development.

This includes drilled or planned drilling of thermal gradient holes and slim wells in the United Republic of Tanzania (thereafter referred to as "Tanzania"), Uganda and Zambia. In Zambia, the drilled slim wells intercepted a geothermal reservoir at a shallow depth, while in Uganda, the drilling of gradient thermal wells was temporarily suspended in April 2020 to allow for the completion of environmental and social impact assessments. Exploration drilling in Rwanda was unsuccessful, and Comoros is in the process of fundraising for exploration drilling.



Various **challenges** have hindered the advancement of geothermal projects among the countries of the EARS over the last decades, including:

- limited awareness about the potential and benefits of direct use applications among policy-makers, entrepreneurs and communities
- limited public financial resources
- challenges in raising financing for the exploration phase – before the resource is proven – notably due to regulatory gaps and lack of adequate policies in some countries
- shortage of local skilled geothermal workforce
- limited understanding of the geology in the Western branch (until recently).

The countries in the region are making commendable efforts to develop their geothermal resources. However, more needs to be done at a faster rate to realise the full potential and benefits of these resources. To this end, collaboration between governments and development partners can help spur geothermal development in the region.

Building on the analysis of experiences in Comoros, Djibouti, Ethiopia, Kenya, Tanzania, Uganda and Zambia, this report draws on lessons learned in these countries and makes the following **main recommendations** to improve enabling frameworks and thereby fast-track the deployment of geothermal energy in the region.

Policies and regulatory framework

- Transparent, clear and predictable licensing and administrative procedures are an essential prerequisite for attracting geothermal developers and investors.
- The establishment of strategic geothermal institutions and departments within energy ministries has been shown to accelerate progress in geothermal development.
- Recent developments in Ethiopia suggest that, with current risk mitigation mechanisms and stable policies, well-structured power purchase agreements can support the early entry of private developers in the financing and implementation of geothermal project.
- Distinct and clear policies and regulations for direct use projects should be enacted.

Financing

- Though finances from the public sector have been instrumental in the realisation of geothermal projects in the region, it is desirable that the private sector get involved as early as possible.
- Risk mitigation schemes and financial support may be considered for both power and direct use projects. Public-private well-productivity insurance schemes could complement existing support mechanisms and encourage development.
- Available and forthcoming financing schemes could be used for raising equity to finance geothermal projects, particularly those in early stage development.
- Technical assistance and project facilitation tools are already available in the region but further support may be required to help some project developers access much-needed affordable finance.
- Purchase of capital-intensive drilling rigs by countries may not be recommended during early geothermal development stages but could be considered after successful exploration to help lower the cost of drilling if the local energy landscape is conducive.

Developing direct use projects

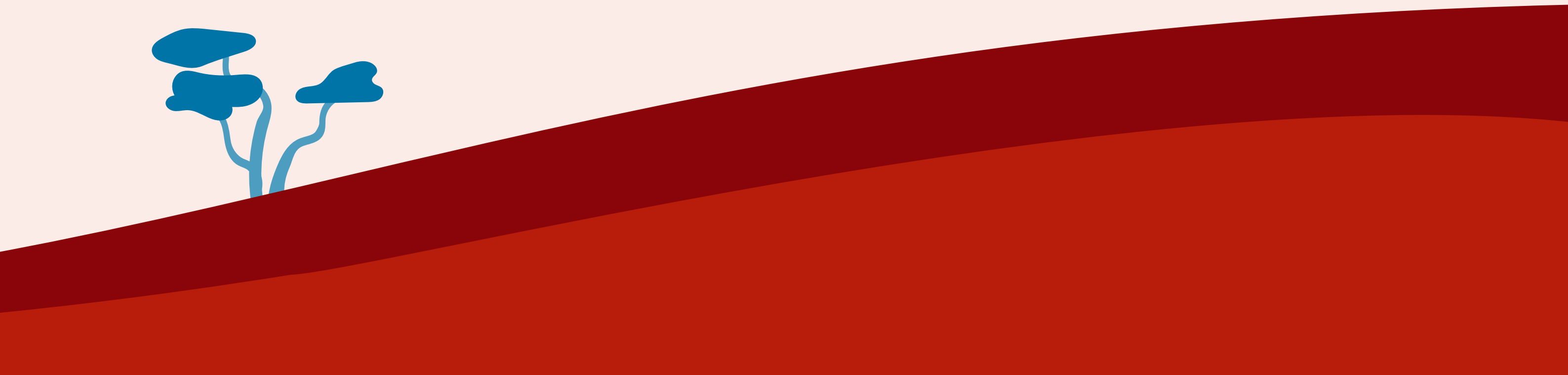
- Awareness creation of the potential for direct use and associated benefits should be targeted towards decision-makers, communities and industries. Appropriate tools to assess the viability of direct use projects should be developed.
- Accelerated development of direct use in the region may benefit from master plans for geothermal heat utilisation for each country that are aligned to industrial and rural development strategies.
- Licensing of direct use projects may be streamlined and regulations clearly spelt out.
- Demonstrating the financial viability of direct use projects and the development of suitable business models should be supported.
- Coordination of the activities of stakeholders could result in quicker development.

Exploration methods

- The appropriate geothermal exploration techniques in the Western branch of the East African Rift will be those focusing on the determination of fault planes and shallow geothermal reservoirs.
- Similar techniques are appropriate for low- to medium-temperature resources in the Eastern branch since most of them are also associated with fractures or fault systems.

Capacity and workforce development

- Training addressing local communities close to the resources, including on environmental issues, may raise awareness, improve social acceptance and open opportunities for direct use projects.
- Training and capacity building for public institutions may be focused on mentoring supporting decision making, rather than imparting only technical or commercial knowledge, especially overseas.
- Sharing of geothermal knowledge and skills among the countries in the region – as is being implemented in Kenya by Kenya Electricity Generating Company PLC (KenGen) and Geothermal Development Company (GDC) through their respective training centres – could contribute to narrowing the technical skill gap in the region. This could also be organised in the framework of the Africa Geothermal Centre of Excellence.



1.

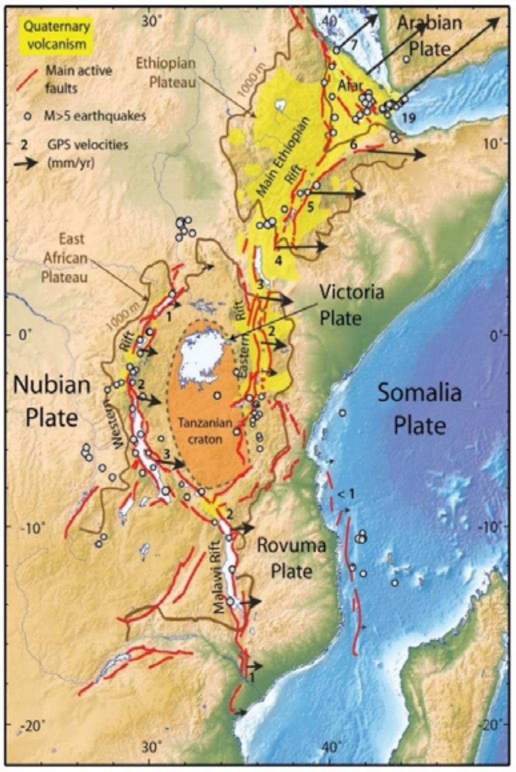
1. INTRODUCTION

Geothermal energy occurs as heat in the crust the earth. It is commonly utilised for generating electricity as well as for direct use (IRENA, 2017a). Geothermal energy is present in areas where tectonism and volcanism have brought magma closer to the surface.

Such areas in Africa include the East African Rift System (EARS) and the Comoros Islands, where temperatures as high as 400°C (degrees Celsius) have been recorded at depths of about 2 300 metres (m). As groundwater circulates in permeable rocks through convection, hydrothermal geothermal reservoirs are formed. Geothermal energy is considered to be a renewable energy source because the heat within the crust continuously flows towards the surface.

Geothermal resources are widely available in the EARS (Figure 1)[1] and may play a key role in improving the low energy access rate in the region. Furthermore, geothermal energy may help governments in the region meet multiple Sustainable Development Goals (SDGs) and the climate objectives set under the Paris Agreement. As of May 2020, however, Kenya was the only country in the region with operational geothermal power plants, with direct use of geothermal resources developed at commercial scale only occurring in limited cases.

Figure 1: The East African Rift System structural map



Source: Calais (2016)

Note: Geothermal sites are found along active faults (red lines) and active volcanic areas (yellow shading). The numbers represent the tectonic plate motions (in mm [millimetres]/year) within the African continent.

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

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[1] The East Africa Rift System (EARS) traverses the region from the Red Sea to Mozambique. It consists of two main sections: the eastern branch, which passes through Djibouti, Eritrea, Ethiopia, Kenya and Northern Tanzania, and the western branch, which passes through Burundi, Eastern DRC, Malawi, Mozambique, Rwanda, Uganda, the Tanzania and Zambia.

This regional assessment of geothermal development for electricity and direct use in the countries of the East African Rift and the Comoros was carried out under the umbrella of the Global Geothermal Alliance. The main objectives were to provide an updated overview of geothermal development in selected countries of the East African Rift region (Figure 2), identify bottlenecks hindering further development, and provide key recommendations to policy makers and key stakeholders regarding possible options to accelerate the deployment of geothermal energy in the region.

Figure 2: Selected countries of the East Africa Rift region covered in the assessment

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This assessment follows similar analyses developed by partners of the Global Geothermal Alliance in other regions of the world and was developed in consultation with the main geothermal actors active in the region to share lessons learned as well as the perspectives of key stakeholders. The recognition of the need for assessment of regional geothermal development in the East African Rift countries was one of the outcomes of the Regional Workshop on Geothermal Financing and Risk Mitigation in Africa.

The workshop, coorganised by the International Renewable Energy Agency (IRENA), the governments of Kenya and Japan, and the Africa Union Commission, was held in Kenya in January-February 2018. The assessment was drawn chiefly from experience in Comoros, Djibouti, Ethiopia, Kenya, Tanzania, Uganda and Zambia, but its recommendations are valid for all countries in the region.

Data collection for the study involved desktop research, including reports available from government ministries and agencies, IRENA, and Organisation for Economic Co-operation and Development (OECD)/ International Energy Agency databases and conference proceedings. Furthermore, tailored questionnaires were prepared to collect information from geothermal developers, independent power producers (IPPs), energy ministries, relevant non-energy state agencies (including agriculture and industrial development departments), selected local authorities, regional and international organisations, and development partners. Preliminary results from this work were captured in a consultation document presented and discussed with stakeholders in October and November 2019.

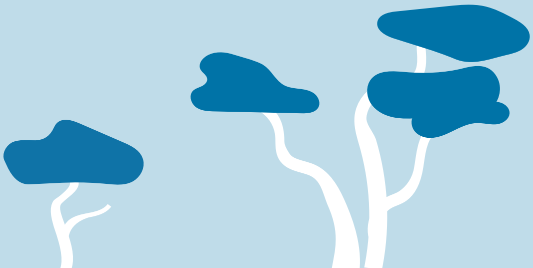
This report is structured as follows: **Chapter 2** provides an overview of the energy trends in 13 EARS countries and a discussion of the role of geothermal in the energy mix and economic development of the region.

Chapter 3 provides an overview of the evolution of geothermal development in the region and presents an in-depth analysis for selected countries in the region, namely Comoros, Djibouti, Ethiopia, Kenya, Tanzania Uganda, and Zambia. **Chapter 4** discusses policies, regulatory frameworks and incentives that are currently in place and recommended to fast-track geothermal project development in the region. **Chapter 5** discusses various strategies and options for financing geothermal projects as well as the financing agencies and programmes that support geothermal projects in the region.

Chapter 6 analyses the challenges facing geothermal direct use and discusses some options to enable and enhance the uptake of direct use projects in the region. **Chapter 7** presents the status of knowledge about the most appropriate exploration methods for different geothermal systems in the region. **Chapter 8** discusses capacity and workforce development requirements for power and direct use projects.

Lastly, **Chapter 9** summarises the challenges and recommendations covering policy and regulatory frameworks, financing, direct use development, geothermal exploration methods, and workforce development.

2.



2. ENERGY SECTOR LANDSCAPE

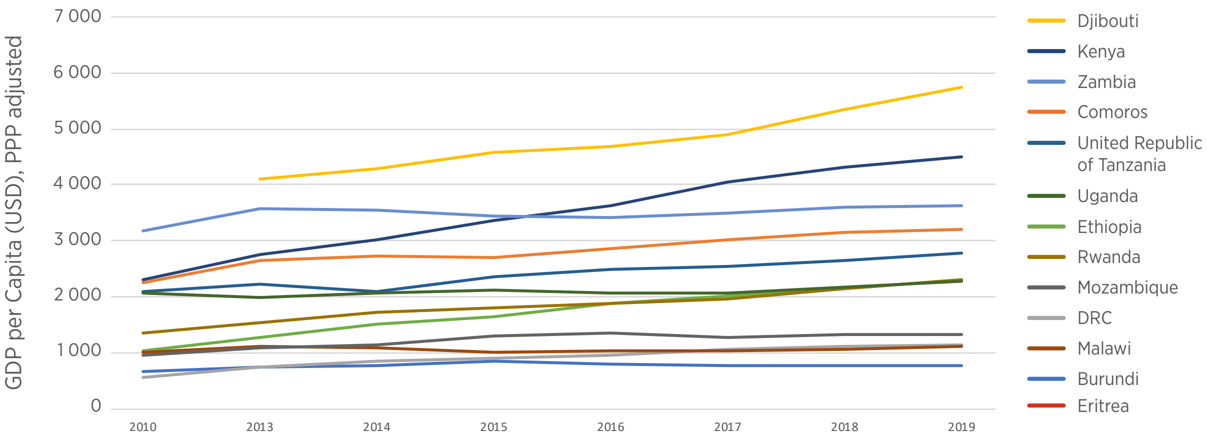
The East African Rift countries and the Comoros Islands are endowed with several sources of energy for which distribution and potential vary significantly from country to country. A government's decision to render support to a given energy resource – e.g. geothermal – is influenced by many factors, including its availability and competitiveness in relation to other energy sources. Therefore, it is imperative to discuss the place of geothermal in the context of the wider energy landscape in the region. To this end, the following sections provide an overview of the energy landscape for the 13 EARS countries: Burundi, Comoros, DRC, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda and Zambia (see Figure 2). The chapter also discusses the specific niche of geothermal in the energy mix and economic development of the region.

2.1 Macroeconomic overview

The countries of the East African Rift region experienced the most vigorous economic growth in Africa in 2018. The recorded average regional gross domestic product (GDP) growth rate of 6.2% was higher than the African average growth rate of 3.4% and the global average growth rate of 3.2%. This growth was mostly driven by rising government spending on infrastructure and growing domestic demand for commodities and services, mainly in Djibouti, Ethiopia, Kenya, Rwanda, Tanzania and Uganda (UNECA, 2019). The GDP per capita for the region varied substantially among the countries, with Burundi reporting values below USD 1000 (US dollars) while Djibouti and Kenya were above USD 4000 in 2019 as illustrated in Figure 3 (World Bank, 2019).

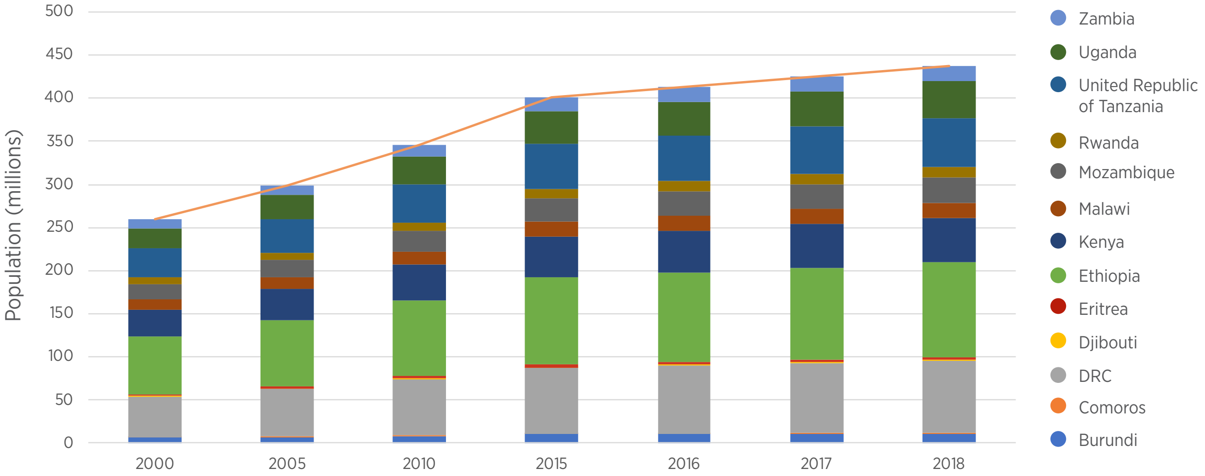
The population in the sub-region was estimated to be 437 million people in 2018 as shown in Figure 4 (World Bank, 2019). Between 2010 and 2018, the annual population growth rate averaged 2.8%.

Figure 3: GDP per capita trends for the East African Rift countries



Based on: World Bank (2020)

Figure 4: Population trends for the East African Rift countries



Based on: World Bank (2019)

2.2 Overview of the regional energy sector institutions and initiatives

Regional organisations and governments in Africa have established several regional initiatives and programmes to support energy development. These include power generation and transmission, promotion of sustainable energy, and capacity development.

Regional power pools and initiatives/programmes have also been created through partnerships between the governments, power utilities and development partners to address the various bottlenecks constraining the energy sector in the region such as low access to modern sources of energy, slow development of energy infrastructure, insufficient financing and investment, and high tariffs for electricity (Nalule, 2016).

Regional power pools

The power pools are designated to plan and co-ordinate the development of power generation and transmission infrastructure in the region. Countries along the EARS fall within the Eastern Africa Power Pool (EAPP), Central African Power Pool (CAPP) and Southern African Power Pool (SAPP).

The DRC is a member of all three power pools, while Tanzania is a member of EAPP and SAPP and Burundi is a member of EAPP and CAPP. Given its status as an island, Comoros does not belong to any of the power pools.

Eastern Africa Power Pool (EAPP)

The EAPP is composed of national power utilities, IPPs, independent transmission companies (ITCs) and other relevant service providers operating in 11 countries in eastern Africa:[2] Burundi (Water and Electricity Production and Distribution Board - Regideso), DRC (National Electricity Co. - SNEL), Egypt (Egyptian Electricity Holding Co.), Ethiopia (Ethiopian Electric Power), Kenya (Kenya Power and Lighting Co., Kenya Electricity Generating Co. and Kenya Electricity Transmission Co. Ltd), Libya (General Electricity Co. of Libya), Rwanda (Energy Water and Sanitation Authority), South Sudan, Sudan (Sudanese Electricity Transmission Co. and Ministry of Water Resources and Electricity), Tanzania (Tanzania Electricity Supply Co. Ltd), Uganda (Uganda Electricity Transmission Co. Limited), and the International Society of Electricity of the Great Lakes Countries - SNELAC of the Economic Community of the Great Lakes Region (Tesfaye, 2014).

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[2] According to COMESA, eastern Africa also includes Libya and Egypt, which are geographically located in North Africa, as well as the Republic of Sudan.

The EAPP was designated in 2006 as an institution of the Common Market for Eastern and Southern Africa (COMESA) with the objective of supporting member countries to improve electrification rates through coordinated development of power generation projects and electricity grid interconnectivity. The execution of this mandate is expected to result in the co-ordinated planning of electricity generation and transmission projects, development of a common grid code to enable exchange of electricity between utilities, and reduced power supply cost in the region.

Southern African Power Pool (SAPP)

The SAPP was created in 1995 in the framework of the Southern Africa Development Community (SADC) to support efficient utilisation of energy resources among SADC member states. Membership is composed of national power utilities, IPPs, ITCs and other relevant service providers of the 12 continental SADC countries: Angola (National Electricity Transmission Network - RNT), Botswana (Botswana Power Corp.), DRC (SNEL), Eswatini (Eswatini Electricity Co.), Lesotho (Lesotho Electricity Corp.), Malawi (Electricity Supply Corp. of Malawi), Mozambique (Mozambique Transmission Co.), Namibia (Nam Power), South Africa (Electricity Supply Commission - ESKOM), Tanzania (Tanzania Electricity Supply Co. Ltd), Zambia (Lunsemfwa Hydro Power Co., Copperbelt Energy Coop. and ZESCO) and Zimbabwe (Zimbabwe Electricity Supply Authority) (SAPP, 2020).

Central African Power Pool (CAPP)

CAPP was launched in 2003 in the framework of the Economic Community of Central African States (ECCAS) to implement energy policy, co-ordinate the expansion of power networks and generation plants, and establish conducive frameworks to enable trade in electricity among the member states. It is composed of the utilities of ten Central African states: Angola (Empresa Nacional de Electricidade and Empresa de Distribucaode Electricidate), Burundi (Regideso), Cameroon (Energy of Cameroon), Congo (Republic of) (National Electricity co. - SNE), Central Africa Republic (Central African Energy - Enerca), Chad (Chad National Electricity Co. - SNE Chad), the DRC (SNEL), Gabon (Gabon Energy and Water Co. - SEEG), Equatorial Guinea (Equatorial Guinea Electricity Co. - SEGESA) and São Tomé and Príncipe (Water and Electricity Co. - EMAE) (CAPP, 2020).

Regional energy institutions

East African Centre of Excellence for Renewable Energy and Efficiency (EACREEE)

The EACREEE was established in 2016 in the framework of the East African Community (EAC) to support the development of renewable energy and energy efficiency initiatives through the promotion of enabling environment, including policy formulation, capacity building, awareness raising and knowledge management, as well as promotion of investments. The scope of the centre is limited to the six EAC member states (Burundi, Kenya, Rwanda, South Sudan, Tanzania and Uganda) (EACREEE, 2019).

SADC Centre for Renewable Energy and Energy Efficiency (SACREEE)

SACREEE was established in 2015 to promote growth in energy access services and development of local renewable energy resources in the SADC region. In addition, SACREEE was mandated to support the SADC Secretariat in the implementation of the regional Renewable Energy and Energy Efficiency Strategy and Action Plan (REEESAP). Its 16 member countries are Angola, Botswana, Comoros, the DRC, Eswatini, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe.

Institutions of the Economic Community of the Great Lakes Countries (ECGLC)

ECGLC is a sub-regional body launched in 1976 to promote inter-state and economic cooperation among Burundi, the DRC (then Zaire) and Rwanda. ECGLC achieves its mandate through its implementing agencies – the ECGLC for Energy (EGL), that does the planning, research and implementation of energy projects – and the International Society of electricity of the Great Lakes (SINELAC), that runs the Ruzizi II hydroelectric power plant and markets the electricity to the three member states through their respective electric utility companies.

Nile Equatorial Lakes Subsidiary Action Programme (NELSAP)

NELSAP's implementation strategy 2017-2027 is a programme under the Nile Basin Initiative (NBI). NELSAP aims, among other things, to support member states to select and develop hydropower generation and electricity interconnection projects to enable regional power transmission and trade. NBI is a transboundary cooperation among the Nile Basin countries of Burundi, the DRC, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda aiming to jointly manage the water of the basin and its related resources.

Inter-governmental energy sector initiatives/ programmes

Africa Clean Energy Corridor Initiative (ACEC)

This initiative was launched in 2014 during the fourth session of the IRENA Assembly to support the penetration of renewable energy within the EAPP and SAPP through project development and cross border trade of electricity. The membership of ACEC includes Angola, Botswana, Burundi, DRC, Djibouti, Egypt, Eswatini, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, South Africa, Sudan, Tanzania, Uganda, Zambia and Zimbabwe.

Africa Union (AU) Energy programmes and initiatives

The AU is a continental intergovernmental organisation established in 2002 to drive Africa's growth and development through integration and cooperation of African states. As part of this mandate, several initiatives have been adopted to drive the energy agenda in the continent. These initiatives are co-ordinated by the union's executive branch, the African Union Commission (AUC).

Programme for Infrastructure Development in Africa (PIDA)

PIDA is a programme co-ordinated by AUC, African Development Bank (AfDB) and AUDA-NEPAD (the development agency of the AU) mandated to develop a pathway for the implementation of key infrastructure projects such as transport corridors, energy projects, trans-boundary water projects, and information and communication technologies on a regional and continental level. PIDA brings together continent-wide infrastructure projects and prioritises them depending on the required development timeframe within a deadline of 2030. PIDA is supporting 54 energy projects in the continent, including hydropower plants and transmission interconnectors in the EARS (PIDA, 2020).

Africa Energy Commission (AFREC)

AFREC was launched in 2008 under the AU to co-ordinate efforts geared towards protection, development, sustainable exploitation, marketing and mainstreaming of energy resources in Africa. Some of its activities include mapping of priority energy projects in Africa, creating and maintaining a continental energy database, and developing inter-Africa trade in energy products.

Africa Renewable Energy Initiative (AREI)

AREI was established under the auspices of the AU following the approval of the member states to accelerate and scale up the development and utilisation of renewable energy in Africa. The AREI aims to mobilise the deployment of 10 gigawatts-electric (GWe) of renewable power by 2020 and an additional 300 GWe by 2030, thereby contributing to universal access to clean energy and climate change mitigation. The AREI target for 2020 was achieved in 2019.

Energy regulators associations

Energy Regulators Association of East Africa (EREA)

EREA is an association of utility regulators in Burundi (Authority for Regulation of Water and Energy Sectors – AREEN), Kenya (Energy and Petroleum Regulatory Authority – EPRA), Rwanda (Rwanda Utilities Regulatory Agency – RURA), South Sudan, Tanzania (Energy and Water Regulatory Authority – EWURA), Uganda (Electricity Regulatory Authority – ERA and the Petroleum Authority of Uganda – PAU) and Zanzibar (Zanzibar Utilities Regulatory Authority – ZURA and Zanzibar Petroleum [Upstream] Regulatory Authority – ZPRA) under the umbrella of the EAC. The objectives of EREA are to pool expertise in energy sector regulation, promote regional cooperation in energy infrastructure planning, encourage capacity building, develop sustainable energy projects and harmonise energy market structures in the region.

The Regional Electricity Regulators Association of Southern Africa (RERA)

RERA brings together electricity regulators from the SADC member states and provides regulatory guidelines to support trading in electricity in Southern Africa. It also enables its members to build their capacity and share information, increasing regional regulatory cooperation. RERA is made up of 16 energy regulators from Angola (Instituto Regulador do Sector Eléctrico – IRSE), Botswana (Botswana Energy Regulatory Authority – BERA), Comoros, Eswatini (Eswatini Energy Regulatory Authority – ESERA), the DRC, Lesotho (Lesotho Electricity and Water Authority – LEWA), Madagascar (Office pour la Regulation de l'Electrification – ORE), Malawi (Malawi Energy Regulatory Authority – MERA), Mauritius (Utility Regulatory Authority – URA), Mozambique (Conselho Nacional de Electricidade – CNELEC), Namibia (Electricity Control Board – ECB), Seychelles (Seychelles Energy Commission – SEC), South Africa (National Energy Regulator – NERSA), Tanzania (Energy and Water Utilities Regulatory Authority – EWURA), Zambia (Energy Regulatory Commission – ERB) and Zimbabwe (Zimbabwe Energy Regulatory Authority – ZERA).

Regional Association of Energy Regulators for Eastern and Southern Africa (RAERESA)

RAERESA is a COMESA institution whose objectives include, among others, capacity building and information sharing, policy and regulatory advice, and facilitation of regional co-operation among regulators. It is composed of energy regulators from 21 countries: Burundi (Agency for Regulation of Water, Electricity and Mining – AREEM), Egypt (Egyptian Electric Utility and Consumer Protection Regulatory Agency – EgyptERA), Ethiopia (Ethiopian Energy Authority – EEA), Kenya (Energy and Petroleum Regulatory Authority – EPRA), Madagascar (Office de Regulation Electricite – ORE), Malawi (Malawi Energy Regulatory Authority – MERA), Mauritius (Utility Regulatory Authority – URA), Rwanda (Rwanda Utilities Regulatory Authority – RURA), Seychelles (Seychelles Energy Commission – SEC), Sudan (Electricity Regulatory Authority – ERA), Uganda (Electricity Regulatory Authority – ERA), Zambia (Energy Regulation Board – ERB) and Zimbabwe (Zimbabwe Energy Regulatory Authority – ZERA).

In addition to the above-mentioned regional institutions, intergovernmental initiatives and programmes, other development partners in the region have developed various initiatives. Some of these include the off-grid initiatives by, among others, Power Africa, the African-EU Partnership, and AfDB initiatives, such as the Sustainable Energy Fund for Africa that supports smaller-sized projects dealing with power generation from renewable energy, and promotion of energy efficiency. Other development partners implementing energy sector initiatives in Africa include the World Bank, UNEP (United Nations Environment Programme) and the UNECA (United Nations Economic Commission for Africa) among others. Dedicated regional programmes put in place by development partners to support geothermal energy are presented in Chapter 5, Section 3 of this report.

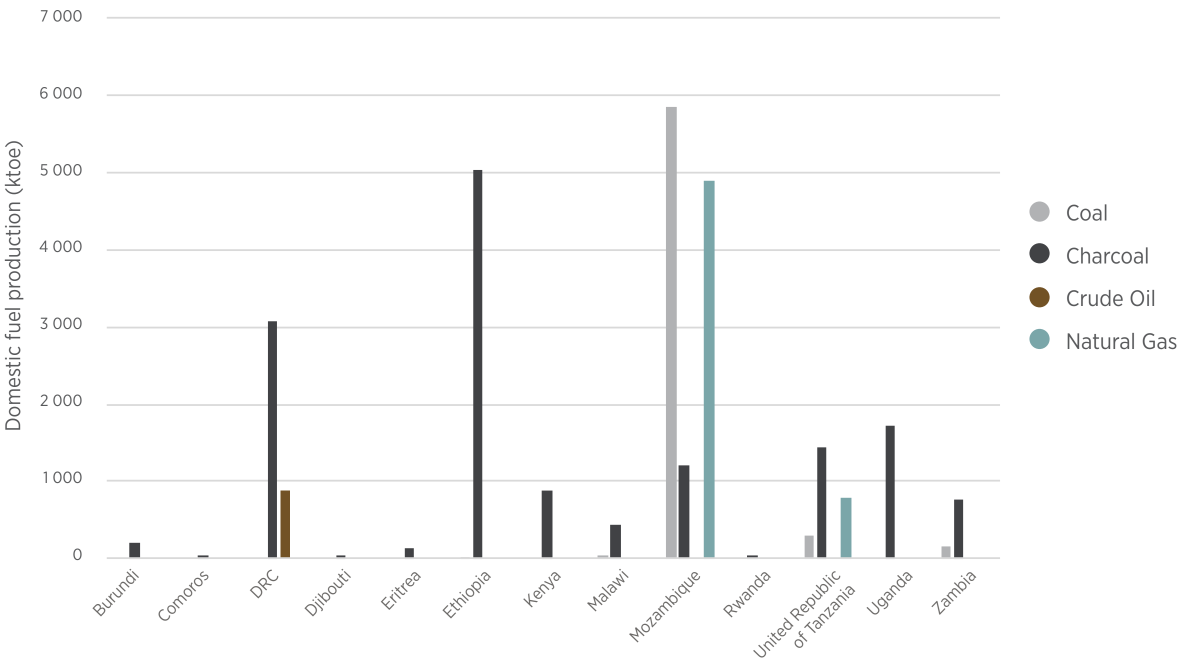
2.3 Overview of energy trends

According to AFREC data, domestic production of fuels in the East Africa Rift countries was estimated to grow on average by 3.5% annually between 2013 and 2018, while electricity generation grew on average by about 4% annually between 2013 and 2017 (IRENA 2019). Charcoal accounts for the largest share of domestic fuels in the region. Other sources of domestic fuels include coal, crude oil and natural gas. The power sector is dominated by renewables, with hydropower being the main source. In 2019, the share of grid-connected capacities for hydropower, geothermal and fossil fuels were 69.4%, 4.2% and 19%, respectively (IRENA, 2020a).

Domestic fuels production

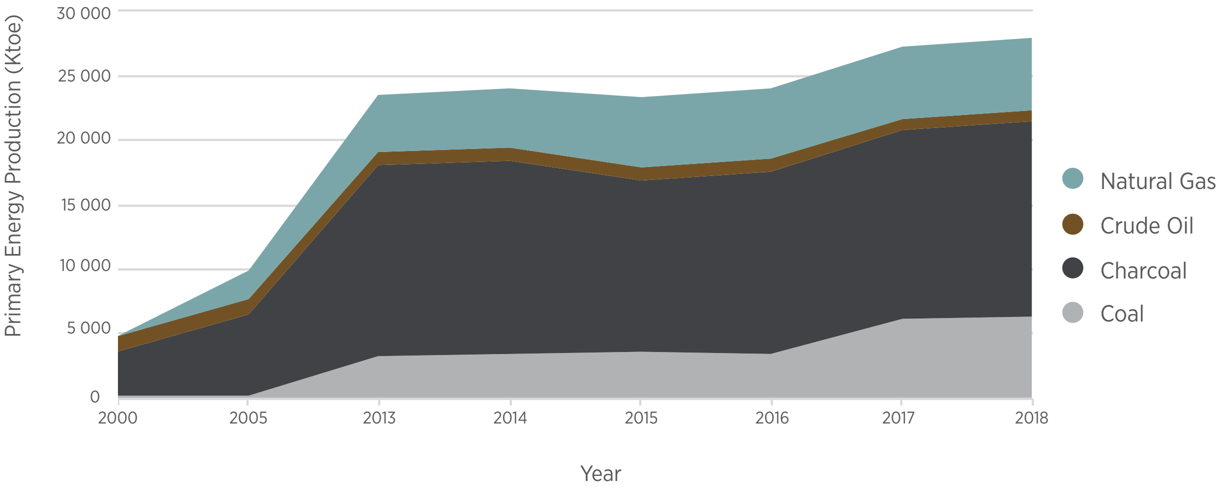
AFREC statistics indicate that domestic fuel production in the East African Rift countries in 2018 was dominated to a large extent by charcoal in all the countries, while coal and natural gas production was significant in Mozambique. Some crude oil was produced in the DRC, and Tanzania had some production of coal and natural gas (Figure 5). Charcoal accounted for about 53% of domestic fuels production, while coal and natural gas accounted for slightly more than 20% each. Crude oil accounted for a little over 3% (AFREC, 2018). The DRC and Ethiopia combined accounted for more than half of the charcoal produced in the region. Charcoal is used mostly for cooking and heating in rural and informal urban settlements, as well as for process heating in a few industries, but is not used for electricity generation. Regional trends and estimates for the East African Rift countries for the period 2000-2018 show growth in the production of domestic fuels. Overall, production increased more than five-fold from about 5 000 kilotonnes of oil equivalent (ktoe) to about 28 000 ktoe driven mainly by charcoal, coal and natural gas (Figure 6). The fastest growth was in charcoal production, while a modest growth for natural gas and coal was recorded. Crude oil production remained nearly constant over the period.

Figure 5: Domestic fuels production estimates by source (2018)



Note: ktoe = kilotonnes of oil equivalent.
Based on: AFREC (2018)

Figure 6: Domestic fuels production trends and projections by source



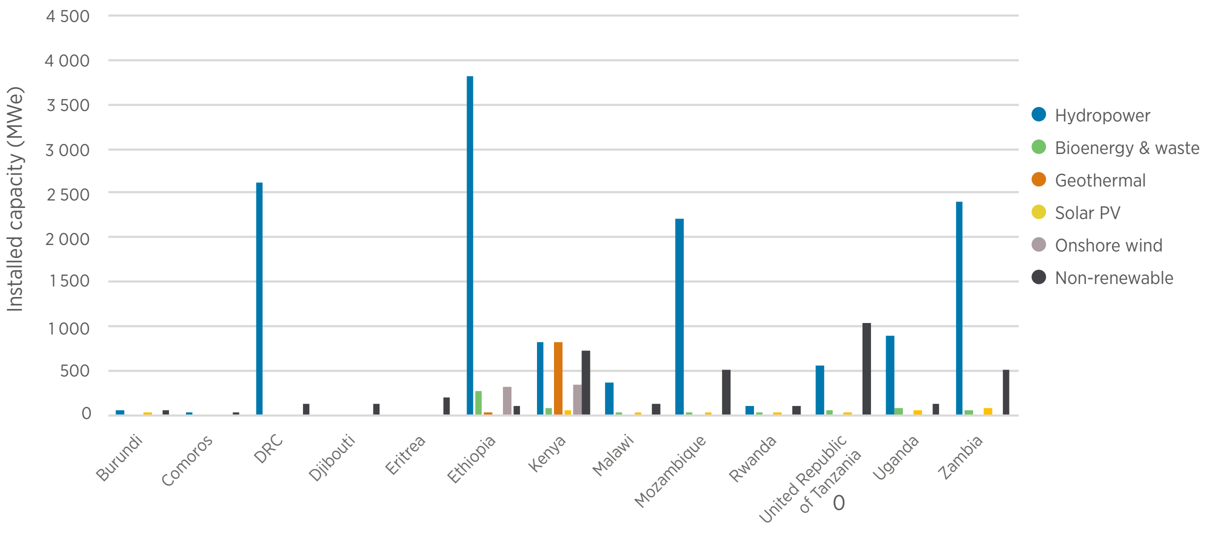
Based on: AFREC (2018)

Grid-connected electricity installed capacity

The electricity sector in the 13 East African Rift countries (see Figure 2) covered in this assessment is still developing. As of December 2019, the sector had a total installed capacity of about 20 000 megawatts electrical (MWe) connected to the grid. Ethiopia had the highest installed capacity, about 4 525 MWe, and Burundi had the least at 98 MWe. Renewables constituted the largest share of installed capacity at 81% while non-renewable energy sources accounted for 19%. Hydropower had the largest share of installed capacity for electricity at around 69.4%, with the largest installations in Ethiopia (3 815 MWe), Zambia (2 400 MWe), the DRC (2 210 MWe) and Mozambique (2 200 MWe). The share of installed geothermal capacity was about 4.2%, with power plants in Kenya (823 MWe) and Ethiopia (7 MWe). Significant wind power installations were found in Ethiopia and Kenya, each having over 300 MWe of installed capacity. Bagasse represented the main source of power from bioenergy in all the countries, with Ethiopia's 25 MWe power plant running on municipal solid waste (IRENA, 2020a) (Figure 7).

Geothermal accounted for about 4.2% of installed capacity as of December 2019, with power plants in Kenya (823 MWe) and Ethiopia (7 MWe).

Figure 7: Grid connected electricity installed capacity (MWe) by source (2019)

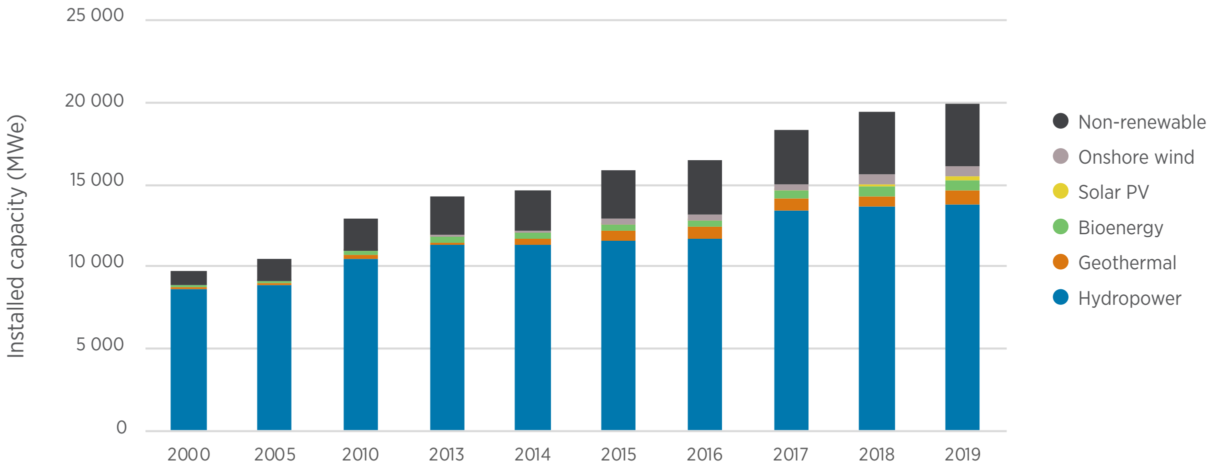


Based on: IRENA (2020a)

In the period 2010-2019, electricity trends for the countries of the East African Rift show that the installed capacity averaged an annual growth rate of 5%. Solar and wind experienced the fastest capacity growth rate, averaging 115.7% and 71.6% annually, respectively, followed by geothermal at an annual average growth rate of 16.8%, non-renewable fuels at around 7%, bioenergy and waste at 11%, and hydropower at 3% annually (Figure 8).

The significant growth in geothermal and wind generation recorded for the period 2014-2019 is due to recent new installations of power plants in Kenya (geothermal) and Ethiopia and Kenya (wind). In 2019, the grid-connected geothermal capacity in Kenya amounted to 823 MWe, following the commissioning of additional power plants in Olkaria.

Figure 8: Grid-connected electricity installed capacity trends by source



Based on: IRENA (2020a)

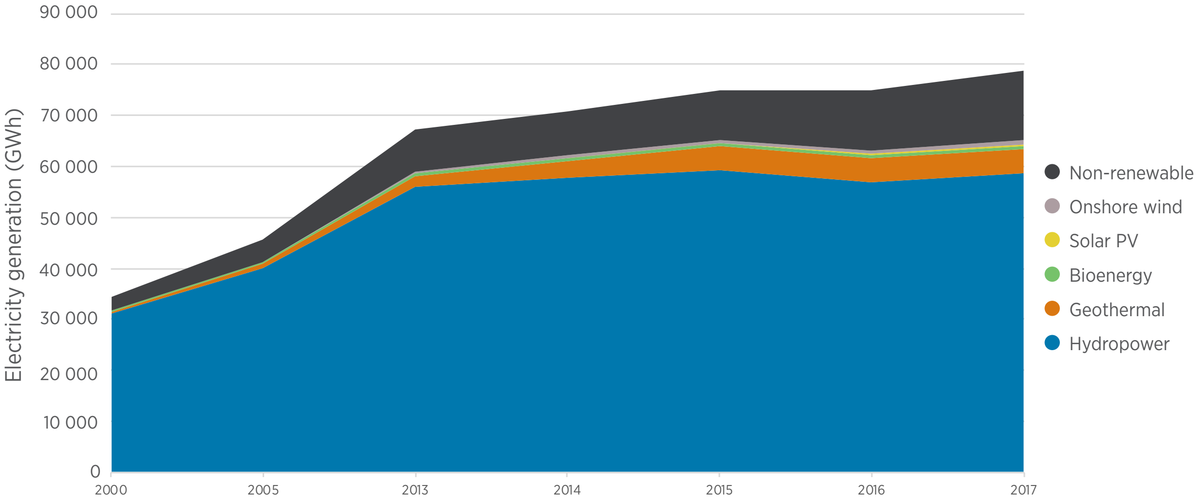
Grid-connected electricity generation capacity

Electricity production in the region was mainly by hydropower sources in all the countries except Comoros, Djibouti, Eritrea and Tanzania, where fossil fuels dominated production.

In 2017, power generated from hydropower sources constituted about 74.4% of the total power generation in the region, while fossil fuels accounted for about 17.4%. Geothermal electricity was generated only in Kenya, accounting, in 2017, for about 6.2% of the electricity produced in the region and 46% of electricity produced in Kenya. Solar and wind generation were recorded at relatively small values in most of the countries except in Comoros, the DRC, Djibouti, Eritrea and Zambia. Electricity from bioenergy and municipal waste was minimal and accounted for 0.8% of the total production. The annual growth rate in electricity generation averaged 4.4% over the period 2010-2017, increasing from about 58 000 gigawatt-hours (GWh) to 79 000 GWh. Most of this growth was driven by hydropower production, which increased by about 9 500 GWh. Non-renewable electricity generation increased by about 6 500 GWh, and geothermal increased by about 3 500 GWh, as shown in Figure 9.

> Geothermal electricity was generated only in Kenya, accounting, in 2017, for about 6.2% of the electricity produced in the region and 46% of electricity produced in Kenya

Figure 9: Grid-connected electricity generation capacity trends by source



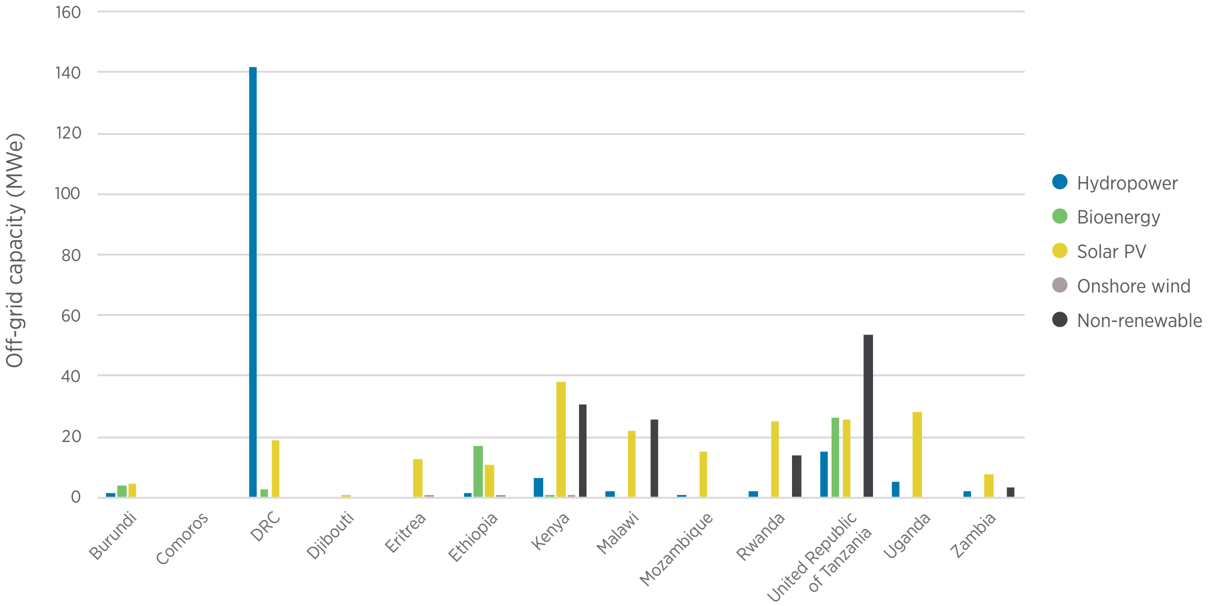
Based on: IRENA (2019c)

Off-grid power systems in the East African Rift countries

Off-grid systems are rapidly growing around the world, and in the process are contributing to the achievement of universal access to modern sources of energy (SDG 7). Although the application of the off-grid systems is mainly in household electrification, the systems are now providing power for industrial and commercial purposes including in healthcare facilities and schools, as well as for productive uses such as agriculture. This, in turn, contributes to the realisation of other SDGs, including building prosperous societies by minimising poverty (SDG 1); securing the availability of food for all and promoting sustainable agricultural practices to put an end to hunger (SDG 2); promoting access to health services for the well-being of societies (SDG 3); and provision of water and sanitary services (SDG 6) (IRENA, 2016a). The off-grid systems are used almost exclusively to provide power through solar lighting, solar home systems, solar and hydropower mini-grids, as well as cogeneration solutions.

The installed off-grid capacity in countries of the East African Rift in 2019 was about 570 MWe. As illustrated in Figure 10, most of the off-grid capacity is in the DRC (163 MWe), Tanzania (121 MWe) and Kenya (75 MWe). Comoros has no reported off-grid installation. Solar photovoltaic (PV) (208 MWe) and hydropower (179 MWe) were the most common off-grid technologies installed in the region.

Figure 10: Off-grid installed capacity by source (2019)



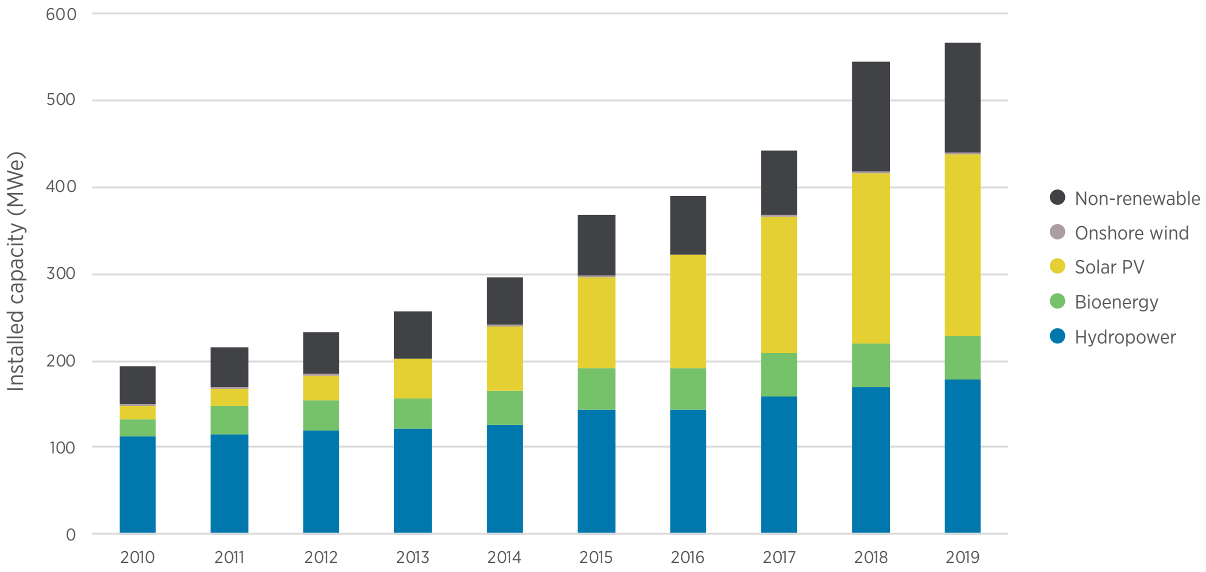
Based on: IRENA (2020a)

In the period 2010-2019, the installed capacity of off-grid power in the region grew on average by about 12.7% annually, from about 200 MWe. Solar PV solutions had the strongest growth, averaging about 33% annually, while non-renewables and bioenergy averaged about 12% each as illustrated in Figure 11 (IRENA, 2020a).

East Africa is the leader in the market share for off-grid solar home systems, accounting for 57% of the global solar off-grid systems investment of USD 284 million in 2017 (IRENA, 2018). This growth was driven by the abundance of the solar resource in the region, decreasing prices of solar equipment, involvement of local and foreign private entrepreneurs, and innovative delivery and financing models which made the solutions affordable.

Innovative supply chain and financing options – such as pay-as-you-go – and microfinancing options also contributed to the growth of solar off-grid systems. Drawing on experiences derived from the deployment of off-grid systems for households, efforts are being made by the private sector to develop off-grid solutions for productive use in sectors such as agriculture and industries.

Figure 11: Off-grid electricity trends



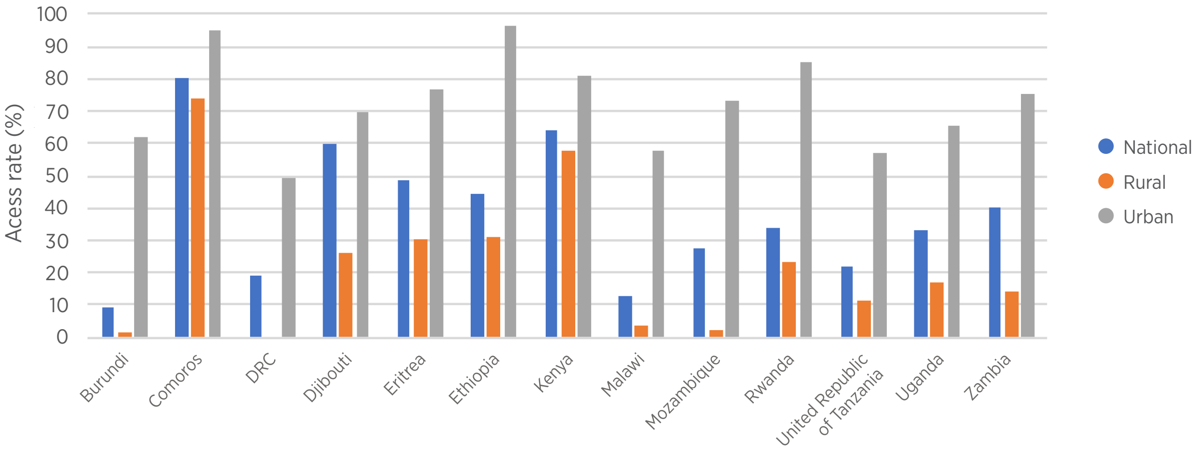
Source: IRENA (2020a)

Electrification rate

The rate of access to electricity in the East African Rift region varies significantly across countries. According to the United Nations Statistics Division (UNStats), in 2017 Burundi had the lowest rate nationally of access to electricity in the region at 9%, and Comoros had the highest rate at 80%. Other than Comoros, Djibouti (at 60%) and Kenya (64%), the national electrification rate in all the other countries in the region was below 50% (Figure 12).

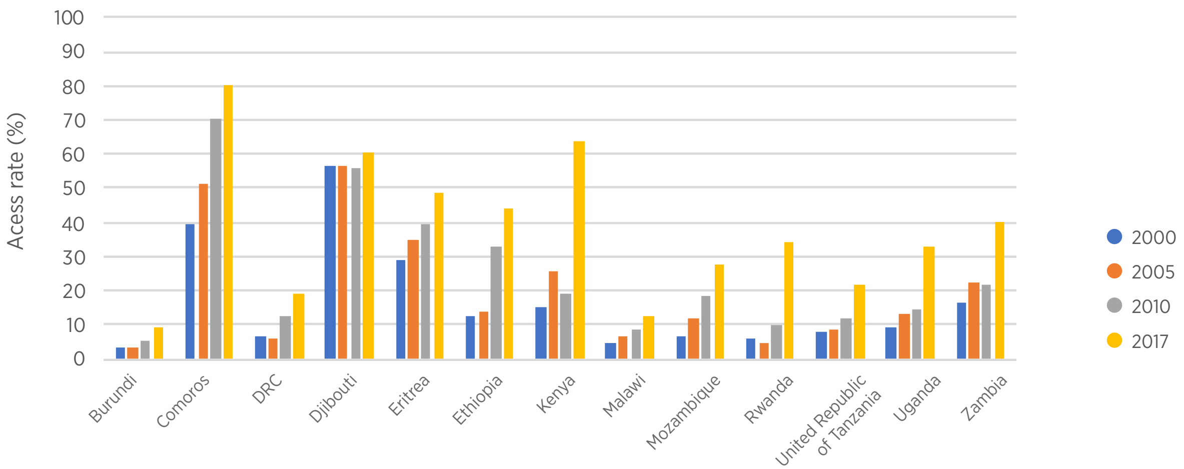
The rate of electrification in urban areas was substantially higher than in rural areas for all the countries. DRC had the lowest urban access rates at 49%, while Ethiopia had the highest urban access rates at 97%. Rural access rates in Burundi, DRC, Malawi and Zambia were below 10% (UNStats, 2019). East African Rift countries had a low rate of electricity access compared to the global average, which corresponded to 89%, 97% and 79% for national, urban and rural areas, respectively, in 2017 (IEA, IRENA, UNSD, WB, WHO, 2019). Despite all the countries recording improved electricity access rates between 2000 and 2017 (Figure 13), data from IEA indicate that out of a population of more than 400 million in the region, more than 284 million were still without access to electricity in 2017 (IEA, 2017).

Figure 12: Electrification rate (national, urban and rural setting) (2017)



Based on: UNStats (2019)

Figure 13: National electricity access trends



Based on: UNStats (2019)

Regional power pools perspective

As reported in Chapter 2, Section 1, countries along the East Africa Rift fall within the following power pools: Central African Power Pool (CAPP), Eastern Africa Power Pool (EAPP) and Southern African Power Pool (SAPP). Through the power pools, excess electricity generated in one country can be transmitted to regions in deficit. Electricity is traded through bilateral agreements between countries in the EAPP where a regional electricity market is yet to be fully developed, *e.g.*, DRC-Burundi-Rwanda, Kenya-Ethiopia, Kenya-Uganda, Uganda-Tanzania, Ethiopia-Djibouti and Ethiopia-Sudan (IRENA, 2017b). In the SAPP, an electricity market is in place that allows trade in electricity. Presently, the electricity traded (total gross import) through the EAPP and SAPP is estimated to be about 30 terawatt-hours (TWh) and represents about 7% of the total electric power demand in the two power pools. Most of the trade in electricity takes place in the SAPP, representing about 12% of the total final electricity demand (EAPP, 2014; SAPP, 2017; Aurecon, 2018). Plans to build additional interconnectors to facilitate further electricity trade among the countries are underway in the region.

The EAPP and SAPP have developed masterplans that project growth in electricity demand up to 2040 and identify specific power generation and transmission projects to be developed in the framework of the power pools.

Planned renewable power generation projects within the EAPP are dominated by large hydropower projects such as Grand Renaissance and Gibe III in Ethiopia, Ruzizi in Eastern DRC, Karuma and Ayago in Uganda, and Stieglers Gorge in Tanzania. Electricity projects powered by geothermal energy from Djibouti, Ethiopia, Kenya and Uganda with a total capacity of 2295 MWe have been earmarked for development under the EAPP. Expansion of natural gas from Lake Kivu in Rwanda is also expected to contribute to the region's electricity supply. Within the CAPP, the emphasis is on small hydropower, solar PV and other renewables.

The power transmission lines interconnecting the countries of the East Africa Rift in the framework of the power pools include Tanzania-Uganda, Rwanda-Uganda, Kenya-Uganda, Kenya-Tanzania, Ethiopia-Sudan, Ethiopia-Kenya, Djibouti-Ethiopia, Mozambique-Zambia, Tanzania-Zambia and DRC-Zambia. Whereas most of these interconnectors are in existence, Tanzania-Zambia and the Kenya-Tanzania lines have been committed for development. Once completed, Tanzania-Zambia interconnector will interconnect the SAPP with the EAPP. Figure 14 depicts some of the existing and planned interconnectors in the region that have reached financial closure and are in the current government plans or bilateral/regional agreements. The indicated power capacity (MW) refers to the maximum power that can be transmitted through the interconnectors.

Other interconnectors for the region include the Rusumo-Rwanda-Burundi-Tanzania line – which is associated with the Rusumo Falls Hydropower Plant (90 MWe) and will interconnect the grids of Burundi, Rwanda, and Tanzania; and the Uganda-DRC (Nkenda-Beni Butembo-Bunia) Power Transmission Line (IRENA, 2017b). Also, under development is the Rwanda-DRC interconnector (Ministry of Infrastructure - Rwanda, 2019).

Building the power infrastructure projects in the framework of the power pools will contribute to addressing some of the challenges in the regional power sector, including low electrification rates, and could enable surplus electricity generated to be exported to the neighbouring countries.

Figure 14: The EAPP and SAPP interconnectors (2019)

		Capacity (MW)
Zambia - Zimbabwe	[Zizabona] Livingstone - Victoria Falls, 330AC Kariba North-Kariba South, 330AC	400 1 400
Tanzania - Zambia	[ZTK] Kasama Nakonde-Tunduma Mbeya, 400AC	750
Tanzania - Uganda	Masaka-Kyaka, 132AC/220AC	431
South Africa - Zimbabwe	[Mozisa] Nzhelele-Triangle, 400AC	500
South Africa - Eswatini	Mahamba-Normandie/ Edwalieni-Camden, 132AC/ 400AC	1 344
Rwanda - Uganda	Mbarara-Birembo, 220AC	363
Namibia -Zambia	[Zizabona] Gerus-Sesheke, 400AC	650
Namibia - South Africa	Kokerboom-Aries/ Harib-Aggeneis, 400/220AC Obib-Oranjemond-Gromis 400kV, 400AC	241 750
Mozambique - Zimbabwe	[Mozisa] Inchope (Matambo-Songo)-Orange Grove (Triangle-Msoro), 400AC Songo - Bindura, 400AC	400 500
Mozambique - Zambia	Songo-Msoro, 400AC	200
Mozambique - Eswatini	Maputo-Edwaleni/ Maputo-Edwalieni2/ Matola-Kalanga, 400AC/ 400AC	1 613
Mozambique - South Africa	Apollo-Songo, 533HVDC Maputo (Motraco)-Arnot/ Ressano Garcia-Komatipoort, 400AC/ 132AC	1 200 1 386
Lesotho -South Africa	Maboti-Tweespruit/ Khukhuna-Clarens, 132AC/ 132AC	217
Kenya - Uganda	Bujagali/ Tororo-Lessos, 400AC	400
Kenya - Tanzania	[ZTK] Kenya-Tanzania (Isinya-Arusha) 400AC	600
Ethiopia - Sudan	Existing Sudan-Ethiopia, AC	200
Ethiopia - Kenya	Ethiopia border-Suswa, 500HVDC	2 000
DRC - Zambia	Lumumbashi-Luano, 220AC	120
Djibouti - Ethiopia	Existing Ethiopia-Djibouti, 220AC	180
Botswana - Zimbabwe	[Zizabona] Pandamatenga-Victoria Falls, 330/400AC Phokoje-Insukamini/ Francistown-Marvelm, 400/220AC	400 1 630
Botswana - South Africa	[BOSA] Isang-Watershed B, 400AC Gaborone-Kopfontein/ Gaborone-Spitskop/ Segoditshane-KOFF, 132AC Phokoje-Matimba, 400AC	800 129 420
Angola - Namibia	[ANNA] Omatando-Xangongo/ Baynes-Cahama, 400AC/ 400AC	700

Source: EAPP (2014), SAPP (2017), Aurecon (2018)
Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

Nationally determined contributions (NDCs)

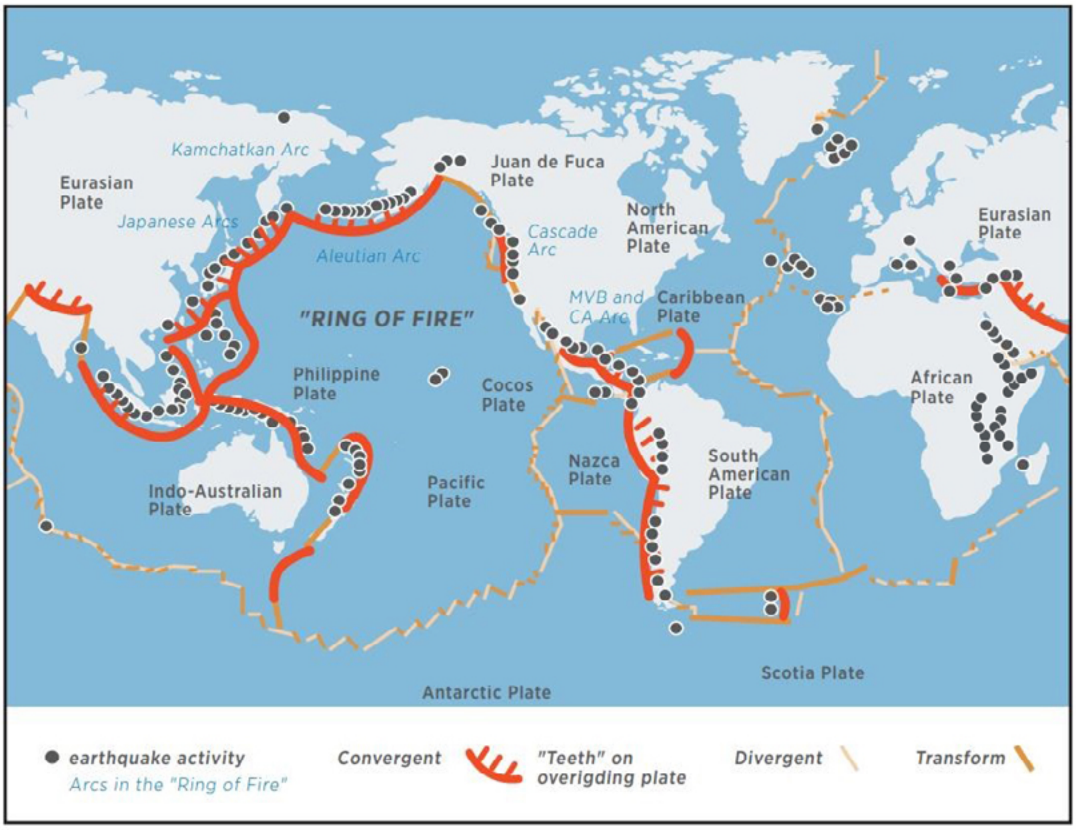
All the countries along the East African Rift view renewable energy as a mitigation measure against climate change and have therefore identified renewable energy solutions as one of the ways of achieving their GHG emissions reduction targets through the NDCs under the 2015 Paris Agreement.

The most referenced source of renewable energy for all the countries is solar PV, followed by hydropower, yet Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Tanzania and Uganda expressly mention expansion of geothermal to realise their NDC targets. Other sources of renewable energy being considered include wind, biomass and biogas (UNFCCC, 2019)

2.4 Role of geothermal energy

The geological context of the EARS provides better resource characteristics than for many other geothermal resources (see Chapter 7 for more details). This is because the EARS is located in a tectonically active zone characterised by a spreading crust and volcanic activities. These conditions contribute to the occurrence of geothermal resources – a renewable resource which can provide energy for the region (Figure 15).

Figure 15: Tectonic plates and global geological activity



Source: IRENA (2017a)

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

One major strength of geothermal energy is that it can be used for multiple applications including direct use of heat, electricity generation, and utilisation of other by-products like recovered mineral elements. This holistic utilisation of geothermal resources, including in other sectors such as agri-food, industries, *etc.*, results in a multiplier effect for social and economic transformation, thereby helping governments meet key development objectives.

Geothermal energy supports direct heat use, power generation and other applications, such as mineral recovery

As is the case with all industrial activities, the development of geothermal resources involves some potential adverse impact on the environment. A particularly relevant aspect concerns how to address the emission of non-condensable gases from geothermal operations. In fact, geothermal energy generates lower or no emission of pollutants and GHGs in comparison to fossil fuel-based power generation.

When binary technology (see Box 1) is deployed in combination with 100% reinjection in a closed loop, ipower and heat can be generated with no emissions. However, there is a growing realisation that geothermal power plants can, in some cases, emit substantial amounts of GHG. It is therefore important to monitor this aspect and put in place all relevant mitigation measures. To that end, ESMAP provides a methodology to assess geothermal emissions, if required, for different stages of development (ESMAP, 2016a).

Furthermore, the GEOENVI project, which is supported by the Horizon 2020 programme of the European Union, highlights the main categories of geothermal related risks as well as the monitoring and mitigation measures that are adopted, or have been tested and are under development, to reduce the probability of adverse effects; and circumvent their consequences to the environment (Menzella *et.al*, 2020).

Geothermal is also an indigenous resource which can reduce imports of fossil fuels, thereby improving the security of supply for those countries with a reliance on fossil fuels and improving commercial balance. Unlike variable renewable energy sources, geothermal provides reliable baseload electric power.

Box 1: Geothermal electricity generation technologies

The technology that is selected to generate electricity from geothermal resources is dependent to a large extent on the enthalpy of the geothermal fluids in the reservoir (Long *et al.*, 2003). Three main technologies are discussed below.

Direct dry steam plants: In these power plants, a steam turbine converts the energy in the geothermal steam into electricity. The condensate collected from the commonly used condensing steam turbines is re-injected into the reservoir or recycled to provide cooling water for the power plant (IEA ETSAP, 2010). Use of direct steam power plants is applicable in geothermal fields producing steam at a temperature of at least 150°C and dryness of at least 99.995% (DiPippo, 2016) to minimise erosion of the power plant equipment.

Flash steam plants: These are the most widely used geothermal power plants, in which steam is obtained by separating the steam-water mixture obtained from a geothermal well through a process referred to as flashing. The steam exiting the turbines after electricity generation is cooled and the resulting condensate re injected or recycled to provide cooling water. The separated geothermal brine can be flashed further at a lower pressure if the temperature and the concentration of dissolved substances allow (DiPippo, 2016). Due to the temperature drop of the fluids associated with the flashing process, flash steam power plants are best suited to geothermal resources with fluid temperatures of at least 180°C.

Binary plants: The operation of a binary power plant requires two fluids – the energy carrying fluid (geothermal fluid) and a working fluid. The two fluids do not mix but transfer heat to each other across a heat exchanger. The geothermal fluid used in the binary power plants, is usually low- or medium-temperature, and heats the working fluid in a closed-loop, converting it to a high-pressure vapour (IEA ETSAP, 2010). The most common types of binary power plants include the Organic Rankine cycles (ORCs) plants which use hydrocarbons and refrigerants as the working fluid, and the Kalina cycles plants which use ammonia/water mixtures as the working fluid. The thermal properties of the working fluid, such as the boiling and condensation temperatures, should be significantly low compared to the temperature of the geothermal fluid (Köhler and Saadat, 2003). The ideal temperature range of geothermal resources that are suitable for the binary power generation is 100°C and 180°C. Below 100°C, the efficiency of the binary power cycles decreases significantly (IRENA, 2017a). The plants can also operate with high-temperature fluids. Ormat has been successfully using high-temperature fluids (>250°C) to run their binary power plants (Ormat Energy Converters) in many locations in the world.

Furthermore, steam or hot water extracted from a well may be converted to electricity directly at the well site, i.e., without pipelines transporting fluids to larger and centralised power plants. Wellhead plants may use either flash or binary generation, and their typical size ranges between 2 MWe and 5 MWe. These plants are usually modular in design with minimal civil works required for their installation.

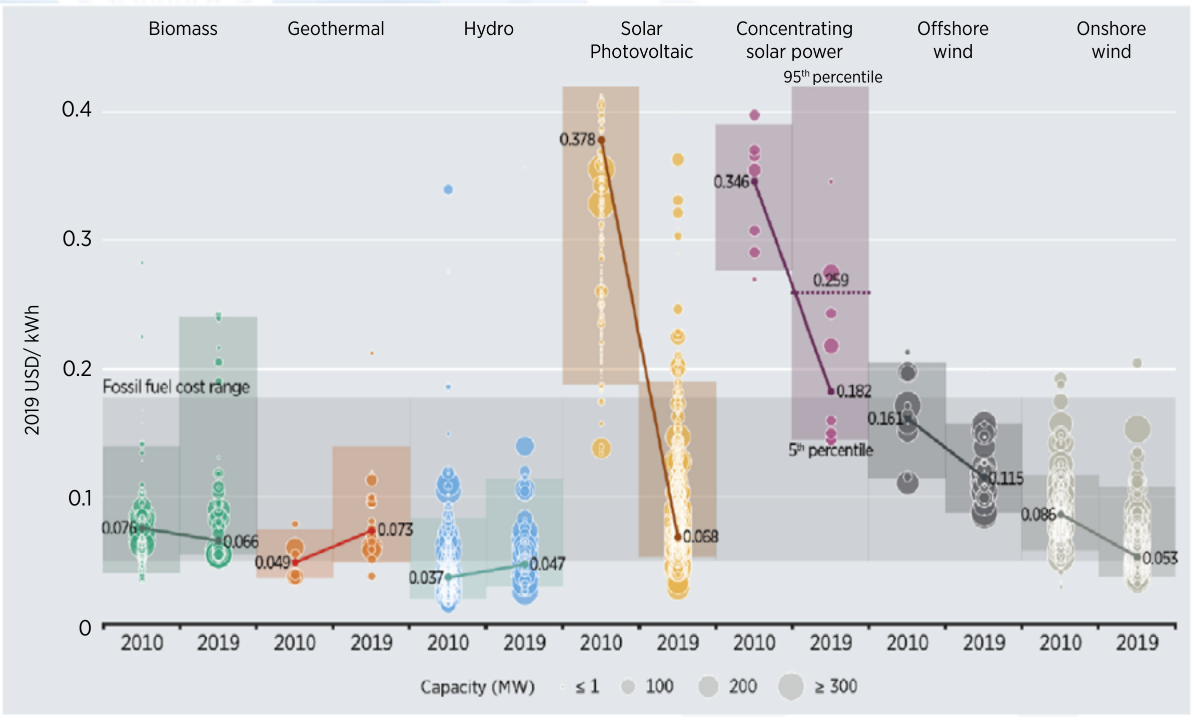
Benefits of wellhead generation include early revenue streams which could support subsequent field development, shorter pipe networks (hence, lower installation cost) and shorter installation periods. The data collected during the operation of the wellhead units could provide valuable information about the geothermal field before further development is undertaken. In addition, the wellhead units provide a platform for training of personnel on power plant operation and maintenance before the main power plant is developed. However, the small-size power plants may at times result in instability of the transmission system and environmental concerns if many units are installed in one field. More than 15 wellhead power plants have been successfully installed at Olkaria, Kenya since 2010.

The levelised cost of geothermal electricity is influenced to a large extent by the site-specific characteristics of the project, the country conditions and the conversion technology for electricity generation (see Box 1). IRENA data reveal that the worldwide levelised cost of electricity (LCOE) for new geothermal installations in 2019 averaged USD 0.073/kilowatt-hour (kWh) (Figure 16).

The total installed cost for geothermal power plants in 2019 averaged USD 3916/kilowatt (USD/kW). However, this varied greatly from a low of about USD 2000/kW to a high of about USD 5000/kW. This takes into consideration the cost of capital, power generation equipment, field infrastructure, surface exploration, drilling operations, installation, grid connection, and operation and maintenance, but excludes taxes.

Binary power plants have a little higher LCOE than flash or steam power plants due to a higher cost of equipment and installation, a lower electrical conversion efficiency, and a lower capacity factor. Furthermore, the average LCOE of geothermal power plants is based on an assumed useful life of 25 years and running costs of around USD 115/kW/year, which among others includes the drilling of two sets of makeup wells to compensate for the decline in productivity over time.

Figure 16: Global LCOE of power generation technologies, 2010-2019



Source: IRENA (2020b)

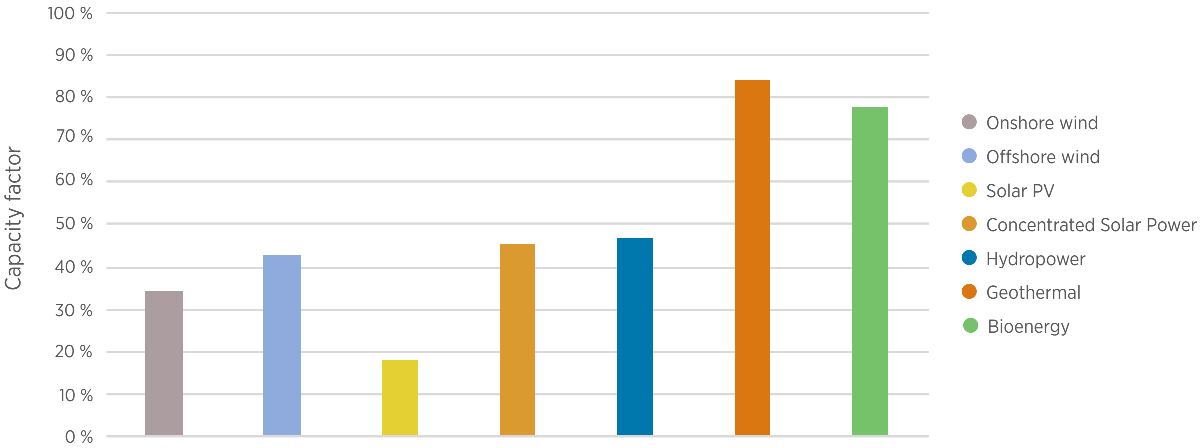
The LCOE of geothermal power plants commissioned in 2019 is in the lower band of the recently built fossil-fuel power projects (IRENA, 2020b). This indicates that geothermal power projects can offer competitive tariffs in comparison to conventional energy sources.

Geothermal energy offers baseload power, which is a major advantage over variable renewable energy sources. This is due to its high availability and capacity factor of more than 80% for geothermal power plants, as shown in Figure 17. Geothermal energy's high capacity factor and availability, as well as the fact that it is readily dispatchable, make it both a complementary option to other renewable energy solutions and one that can be used to balance the variable supply from wind and solar.

One of the challenges related to geothermal energy is the long project lead-time. However, in recent years this been reduced through technological developments on resource exploration and wellhead generation units. Unlike conventional geothermal power plants, the wellhead units (see Box 1) take a shorter time to deploy, as they enable early generation of electricity (such as in Olkaria and Eburru in Kenya) while awaiting further geothermal field development.

Ethiopia is also developing a wellhead power plant in Aluto-Langano to utilise existing steam, even as it plans future expansion of the project. In addition, wellhead units allow for the generation of captive power[3] for industrial/commercial use, as is the case for Oserian Development Company in Naivasha, Kenya.

Figure 17: Weighted capacity factors for power generation technologies



Based on: IRENA (2019c)

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[3] Captive power is generated for localised utilisation by an end-user. The power is generated close to the consumer. A captive power plant may operate parallel to the grid or in off-grid mode.

Taking into account the development of other alternative sources of electricity, it is worth highlighting that the East African Rift countries are likely to suffer greater inconsistent weather patterns that will affect hydropower generation – more so for small run-off-river hydropower projects than dammed hydro due to lack of storage facilities (IPCC, 2008). Most of the countries of the EARS produce the largest share of their electricity from hydropower plants; however, development and generation of hydropower continue to experience challenges, such as heavy siltation likely due to climate change impacts (Kaunda, Kimambo and Neilsen, 2012).

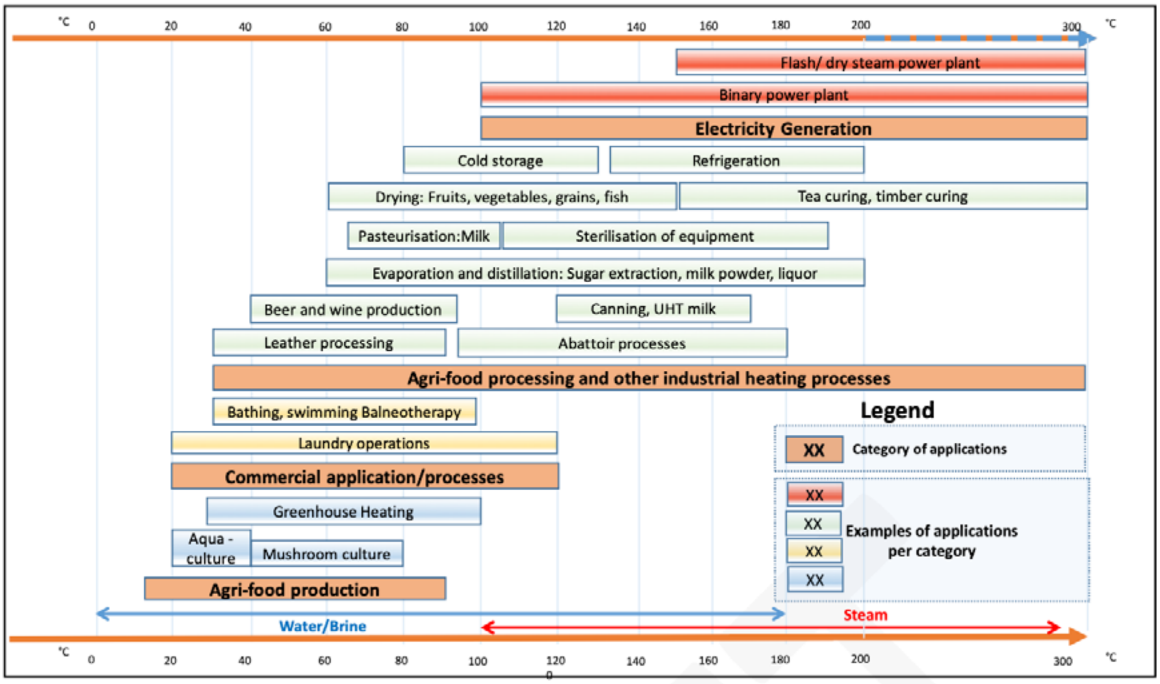
Soaring climatic change will potentially put a strain on water resources, thereby hampering hydropower development along the Nile River and its tributaries, along with other major rivers in the region. The uncertainties and complexities of climate change place a premium on integrative approaches in dealing with water supply and demand changes in the river basins. There is a dramatic need for change in water management and technological advancement to develop project resilient methods in building and designing (Beyene, Lettenmaier and Kabat, 2006).

The latter, however, is subject to continuous research and test-runs over several years for suitability purposes in the East African region (for example, modular hydropower or channelling water flows from municipality facilities or irrigation channels). In addition, disputes among countries over the right to use transboundary water resources such as the Nile River could further hinder or significantly delay the development of future hydropower projects (Hendawi, 2020).

The uncertainty around hydropower developments may provide an opportunity for geothermal capacity to grow, thus catering for the stagnating growth of hydropower in the future.

Beyond electricity, it is important to highlight that geothermal energy can contribute to reduced use of fossil fuels or electricity in some end-use sectors through the deployment of direct use applications. In the East African Rift region, relevant direct use applications include greenhouse and aquaculture heating; drying of agricultural produce such as cereals, fruits and vegetables; pasteurisation of milk; processing of meat and fish; and cooling/refrigeration (Figure 18).

Figure 18: Lindal diagram (modified) on some geothermal direct uses applicable to the East African Rift region



Based on: Lindal (1973)

Direct use applications can also contribute to climate adaptation. For example, geothermal use in greenhouse heating, aquaculture and other agricultural practices could positively impact on food security and could improve incomes, which would help address the extreme poverty of rural communities. Furthermore, geothermal can provide potable water through desalination or condensation of steam on the surface to address water shortages.

Gender inclusivity is addressed by the use of geothermal heat in the agri-food value chains, where women are actively involved in aquaculture, greenhouse farming as well as post-harvest processing, among other activities. Perspectives and recommendations for accelerating the deployment of direct use applications in the region are provided in Chapter 6.

Finally, the insecurity that is rampant in northern Kenya, northeastern Uganda (Karamoja), Afar in Ethiopia and parts of Djibouti and Eritrea is driven by competition for scarce resources such as water and pasture for livestock.

On the other hand, these areas are endowed with geothermal resources, which can be utilised to create alternative economic activities for their populations through direct uses, thus taking pressure off limited pasture and water resources. In this sense, geothermal can be considered as a potential enabler of peace (Varet, 2018; Nebro *et al*., 2016).

3.

3. STATUS OF GEOTHERMAL DEVELOPMENT AT REGIONAL AND COUNTRY LEVELS

The status of geothermal development in the region for both electricity and direct use is briefly discussed in this chapter. This includes an analysis for the following selected countries: Comoros, Djibouti, Ethiopia, Kenya, Tanzania, Uganda and Zambia. The chapter also describes the barriers to the uptake of geothermal energy in each of these countries.

3.1 Regional overview

The total installed electricity capacity from all energy sources in the East African Rift countries is about 20 GWe. The contribution of geothermal energy to this is about 900 MWe, with all the existing installed geothermal power plants located in Kenya and Ethiopia (IRENA, 2020a).

The first geothermal electricity generation plant was developed in the DRC in 1952, and it had an installed capacity of 0.2 MWe (DiPippo, 2012). However, the plant was decommissioned in the 1970s when mining operations for which it was supplying power declined. This was arguably the first binary power plant in the world.

Kenya was the second country to install a geothermal power plant with the 45 MWe Olkaria I power plant coming into operation in 1981-1985. The installed capacity in Kenya has since grown to 880 MWe from several sites. Kenya has continued to lead in geothermal development and, in 2017, geothermal represented about 46% of electricity produced in the country against its installed capacity of about 28%.

Zambia was the third country in Africa to install a geothermal power plant. The 0.2 MWe ORC pilot plant was developed at Kapisya geothermal area in 1986 but has not been commissioned to date – initially due to the absence of a transmission line, but lately due to a breakdown of the production well equipment (Omenda and Zemedkun, 2011). The status of selected geothermal fields/projects in the region is shown in Table 1.

Nearly half of Kenya's electricity production comes from geothermal plants, with installed capacity approaching 900 megawatts.

Table 1: Status of geothermal development in the East African Rift countries (2019)

Country	Project/ Field	Surface studies	Exploration & appraisal drilling	Feasibility study	Production drilling and construction	Ownership	Installed (MWe)	In operation in May 2020	Decommissioned/ Not commissioned (MWe)
Comoros	Karthala	Completed	Planned			Public			
Djibouti	Asal-Fialé	Completed	Done	Ongoing		Public			
	Gale-Le-Koma	Completed	Done			Public			
	North -Ghoubhet	Completed	Planned			Public			
	Arta	Completed	Planned			Public			
	Hanle, Garabayis	Completed	Planned			Public			
	PK20-Ambado	Completed	Planned			Public			
DRC	Kiabukwa	TGH drilled	Shallow well			Private			0.2 MWe
Ethiopia	Aluto-Langano	Completed	Done	70 MWe		Public	8.5 MWe		
	Tendaho-Alalobeda	Completed	Tendered			Public			
	Tendaho-Dubti	Completed	Done	Ongoing		Public			
	Tendaho-Ayrobera	Completed	Planned			Public			
	Corbetti	Completed	Tender			Private			
	Tulu Moye	Completed	Ongoing			Private			
	Fantale, Butajira, Wondo- Genet, Boku, Daguna Fango, Boseti, Abaya, Kone, Dofan, Shala, Abijata, Gedemsa, Mateka	Completed	Planned			Public and private development			

Table 1 (continued)

Country	Project/ Field	Surface studies	Exploration & appraisal drilling	Feasibility study	Production drilling and construction	Ownership	Installed (MWe)	In operation in May 2020	Decommissioned/ Not commissioned (MWe)
Kenya	Olkaria	Completed	Done	140 MWe Olkaria PPP and 280 MWe	83 MWe Olkaria I unit 6	Public, PPP and private	877 MWe	877 MWe	
	Eburru	Completed	Done			Public	2.52 MWe	2.52 MWe	
	Menengai	Completed	Done	60 MWe	105 MWe	PPP			
	Korosi	Completed	Ongoing			Public			
	Paka	Completed	Ongoing			Public			
	Silali	Completed	Planned			Public			
	Akiira	Completed	Done			Private			
	Barrier Volcanic Complex	Completed	Planned			Private			
Rwanda	Karisimbi	Completed	Done			Public			
	Gisenyi	Completed				Public			
	Bugarama	Ongoing				Public			
Tanzania	Kiejo-Mbaka	Completed. TGH drilled	Feasibility study for DU	DU planned		Public			
	Ngozi	Completed	Deep Slim hole planned			Public			
	Songwe	Completed	TGH planned	DU planned		Public			
	Lake Natron	Ongoing				Public			
Uganda	Panyimur	Completed	TGH ongoing			Public			
	Kibiro	Completed	TGH drilling completed			Public			
	Buranga	Completed	TGH planned			Private			
Zambia	Kapisya	TGH drilled	Shallow production well			Public			0.2

Note: PPP = public-private partnership; DU = direct use; TGH = thermal gradient hole.

The 8.5 MWe (7.3 MWe net) pilot power plant in Aluto-Langano geothermal field in Ethiopia was commissioned in 1998. The plant broke down in 2003 and was partially repaired in 2006 but fell into complete disrepair in 2015 due to plant maintenance challenges. Ethiopia has plans to reactivate the Aluto-Langano power plant and expand generation initially to 70 MWe and to a total of about 690 MWe by 2025 (Kebede and Woldemariam, 2018). In parallel, IPPs have completed detailed surface studies and drilling operations started in Tulu Moye in March 2020, while the drilling contract for at Corbetti is expected to be awarded in the last quarter of 2020.

Tanzania, in its power sector planning, envisages installing at least 200 MWe by 2025 from a portfolio of five projects: Ngozi, Kiejo-Mbaka, Songwe, Luhoi and Lake Natron (Kajugus, Kabaka and Mnjokava, 2018). The government is currently mobilising funds for carrying out detailed surface studies and test drilling in some of the prospects.

In Djibouti, the national electricity capacity expansion master plan anticipates that about 400 MWe of geothermal power could be installed by 2037 (World Bank, 2017). Exploration drilling has been undertaken in Djibouti at Asal, Fialé Caldera and Gale-Le-Koma fields.

Exploration for geothermal is also ongoing in Malawi, Rwanda, Uganda and Zambia. Some of these countries are being evaluated for low- to medium-temperature resource development for power generation and/or direct use. Kalahari Energy Limited has drilled some shallow thermal gradient holes in Bwengwa River prospect in Zambia with some positive indications for a low- to medium-temperature resource of up to 150°C at shallow depth that could be suitable for power generation of about 15 MWe using ORC technology within the identified resource area (Vivian-Neal *et al.*, 2018). In Uganda, thermal gradient wells have been drilled at Kibiro to determine the subsurface characteristics of the geothermal resource. If positive results are obtained, it could lead to further development of the expected low- to medium-temperature resource for power generation and direct use.

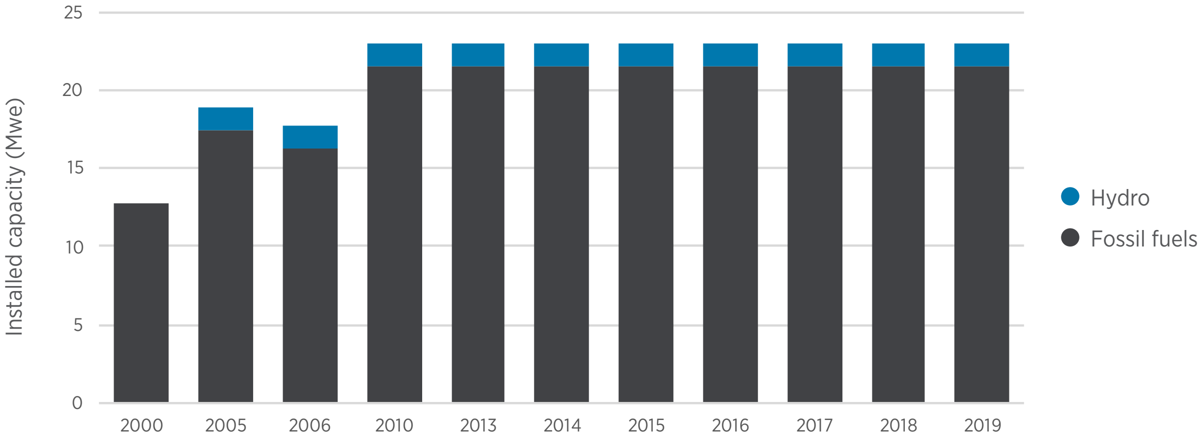
3.2 Status by country

Comoros

Hydropower and fossil fuels are the only grid-connected sources of electricity in the Comoros Islands. The installed capacity of fossil fuel-based sources remained constant during the period 2010-2019 at 21.6 MWe, and similarly, hydropower capacity remained unchanged at 1.4 MWe (Figure 19).

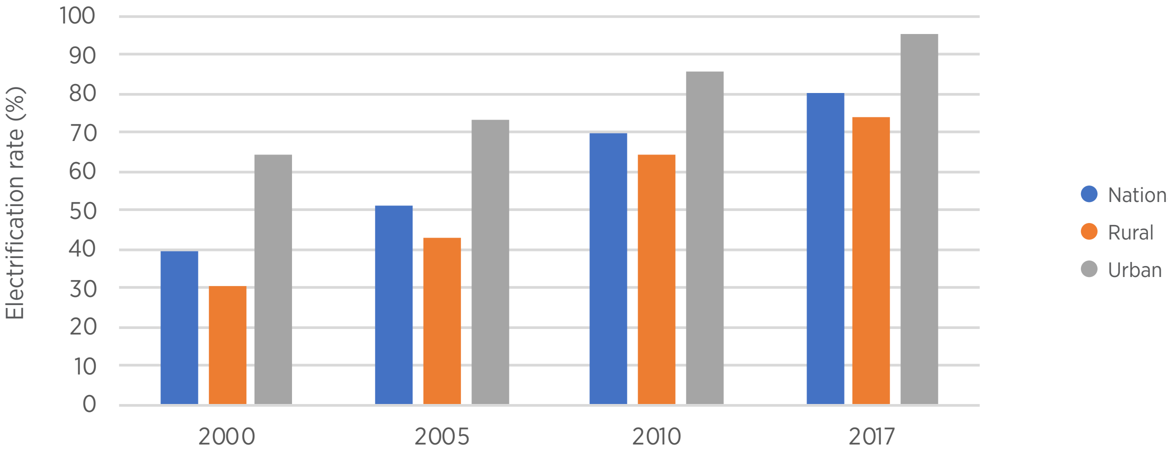
The Comoros Islands had a significant increase in electricity access for urban, rural and national consumers from 2000 to 2019 with an urban electrification rate exceeding 95% in 2017. The national electrification rate was also the highest in the region at 80%, while the rural electrification rate was 74% (Figure 20).

Figure 19: Grid connected installed electricity trends in Comoros by source



Based on: (IRENA, 2020a)

Figure 20: National, urban and rural electricity access trends in Comoros



Based on: UNStats (2019)

As of 2020, there are no geothermal fields in operation in Comoros. Yet the government has shown commitment towards geothermal exploration and development despite the limited financial resources available in the country.

The focus area for geothermal exploration is the Karthala Volcano, located on the main island of Grand Comoro. The other islands have not been evaluated for their geothermal potential. Surface studies that involved geological mapping, geochemistry, magnetotelluric (MT), transient electromagnetic (TEM), gravity and seismic – undertaken in 2015 by the Geological Bureau of Comoros and its partners and financed by the United Nations Development Programme (UNDP), the government of New Zealand and the Geothermal Risk Mitigation Facility (GRMF) – revealed the possible existence of a high-temperature geothermal system under Karthala Volcano estimated to a have potential of producing over 40 MWe (Chaheire, Chamassi and Houmadi, 2016).

Drilling of three deep exploration wells is planned in the high-potential area located to the north of the caldera, with plans to install a 10 MWe generation capacity in the first phase of development. The project cost for drilling three exploration wells and the development of infrastructure is estimated at USD 53 million (Anlil-Wafa *et al.*, 2018). The government of Comoros has obtained financial support of USD 10.87 million from GRMF and USD 6.6 million from the Global Environment Facility (GEF) (GRMF, 2018).

The government, assisted by development partners led by UNDP, is looking for options to reassess the exploration drilling strategy to reduce the expected costs.

UNDP is also supporting Comoros to address various aspects of the energy sector, such as the development of a legal and regulatory framework for renewable energy as well as efforts to raise financing for geothermal exploration drilling. When a new legal and regulatory framework is developed, the role of private investors is expected to be clarified, with supportive mechanisms developed to promote IPP investment in the geothermal sector. In addition to power generation, the planned power project may incorporate some direct use applications.

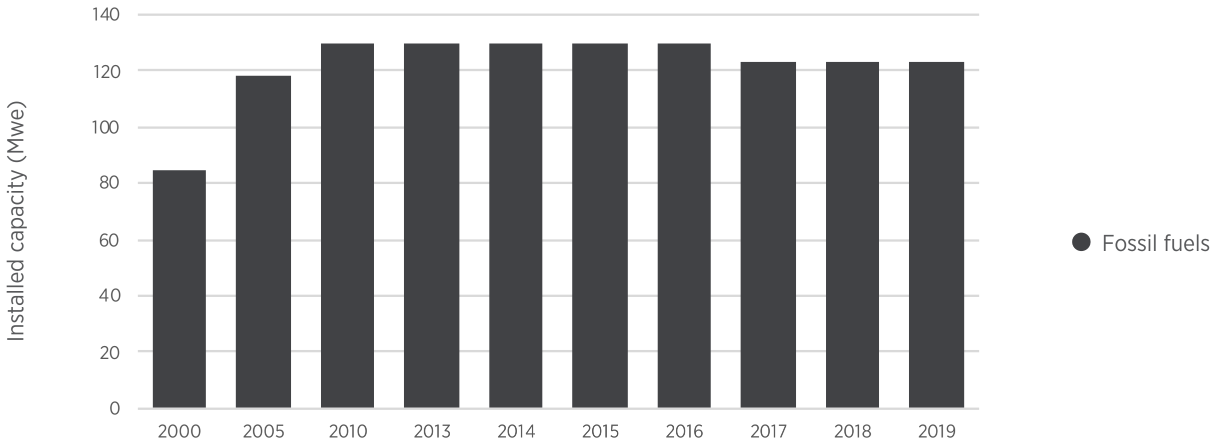
Furthermore, it is worth noting that Comoros has low technical expertise available to implement the geothermal projects successfully. Key technical areas for capacity development include geo-scientific studies, drilling engineering and project management.

Djibouti

As of December 2019, the installed electricity capacity in Djibouti amounted to 123 MWe and was mainly from non-renewable energy sources (Figure 21). The installed capacity was almost constant between 2008 and 2019, but this was supplemented by imported electricity from Ethiopia through a 230 kilovolt line constructed in 2011. Djibouti relies on imported energy electricity with about 70% supplied from hydropower by Ethiopia and the rest from diesel-powered generators (World Bank, 2017). Furthermore, Djibouti has an installed off-grid capacity of 0.3 MWe from solar PV.

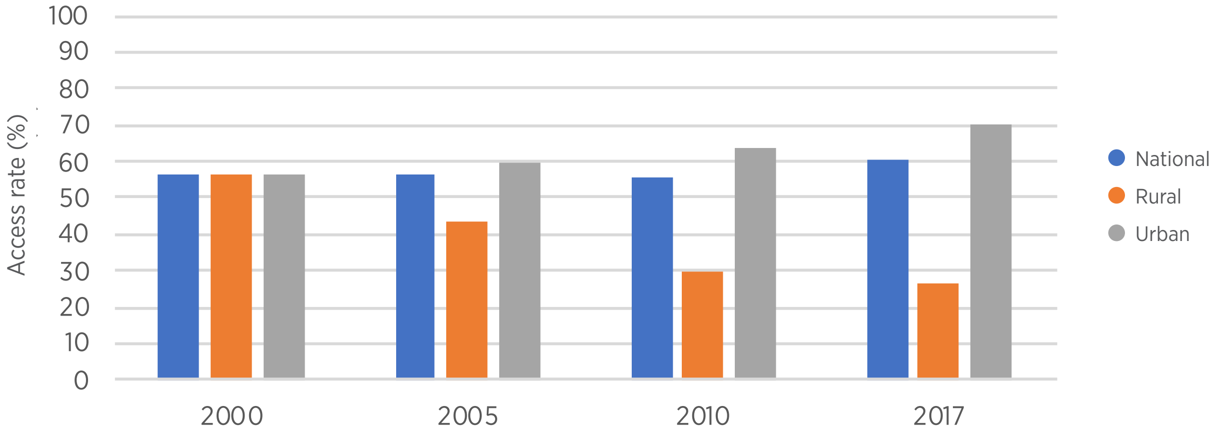
The national electricity access rate in Djibouti increased from about 56% in 2000 to 60% in 2017. However, the rural electrification rate decreased from 56% to 26% during the same period, while in urban areas it increased from 56% in 2000 to 70% in 2017 (Figure 22).

Figure 21: Grid-connected installed electricity trends in Djibouti



Based on: IRENA (2020a)

Figure 22: National, urban and rural electricity access trends in Djibouti



Based on: UNStats (2019)

Resource exploration for geothermal energy commenced in 1970. This resulted in the identification of at least 22 potential geothermal areas. The most promising prospects were found to lie along the main northwest-southeast rift spreading axis of the Afar rift trend. The preliminary studies identified Asal-Ghoubhet as the most promising site, which resulted in the drilling of three deep exploratory wells in 1975 in Asal (Houmed *et al.*, 2012). One of the wells was productive but had very high salinity.

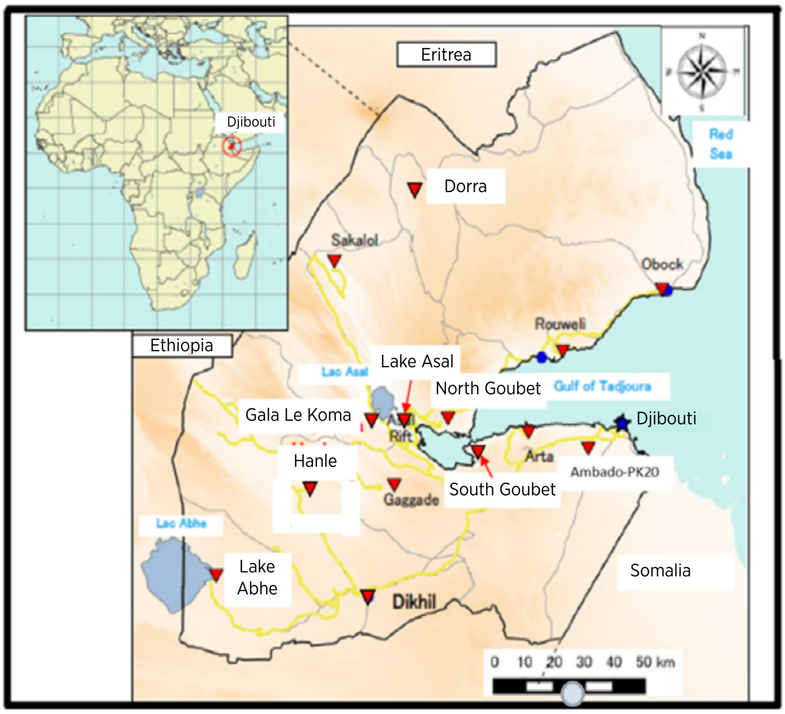
Further exploration studies resulted in the drilling of two exploration wells in 1987-1990 in Hanle and four additional wells in Asal prospect. All the wells have very high salinity. The other prospects are Arta, where surface studies were finalised in 2019 through the government and GRMF funds, North Goubet, Lake Abhe, Obock, Sakalol, and Gaggadé (Figure 23).

Geothermal exploration and development activities slowed down in Djibouti until 2014, when the Djibouti Office for Geothermal Energy Development (ODDEG) was established by the government of Djibouti to focus on geothermal exploration and development.

Public resources are therefore channelled through ODDEG to fast-track geothermal projects in line with the country's Vision 2035. ODDEG has since created a database of the 22 geothermal sites in the country and prioritised them for development.

Since 2016, ODDEG has raised funds to undertake exploration drilling in Gale-Le-Koma, targeting the intermediate reservoir (1 200 m), (the southern part of the Lake Asal geothermal field) and the PK20-Ambado prospects. Additional funds have been raised from the Djibouti government to drill in PK20, and Kuwait Fund and Arab Fund for Economic and Social Development will be used to drill appraisal and production wells in the Lake Asal fields. Finally, the first two or three exploration wells financed by the Japan International Cooperation Agency (JICA) and the Djibouti government will be drilled in Hanle Garabayis, with spud-in planned for 2020 (Kayad, 2019).

Figure 23: Map of geothermal sites in Djibouti



Source: Mohamed, Mousa and Khaireh (2016)
Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

At the initiative of EDD (Electricité de Djibouti), production wells were drilled in Fialé Geothermal field (the northern part of Lake Assal). Financing was provided by the Djibouti government, the African Development Fund (ADF), the Sustainable Energy Fund for Africa (SEFA), the International Development Association (IDA), the GEF and the Energy Sector Management Assistance Programme (ESMAP) (both through the World Bank), the Agence Française de Développement (AFD), and the Organization of Petroleum Exporting Country (OPEC) Funds for International Development (OFID) (Kayad, 2019). Exploration drilling has been undertaken in Asal, Fialé Caldera and Gale-Le-Koma. At Fialé, temperature inversion similar to that recorded in 1986 (Varet, 2014) was observed in all the three deep wells drilled between July 2018 and February 2019.

As of December 2019, all geothermal projects in Djibouti were being developed by ODDEG, which is the state entity charged with the responsibility to manage the country's geothermal resources. However, despite the absence of legislation governing private investment in geothermal energy projects, the Djibouti government through the National Investment Promotion Agency (NIPA) has put in place an interim mechanism to allow IPPs to develop renewable energy projects.

There is no recorded large-scale direct use of geothermal resources in Djibouti, except trapping of steam for water production from steam condensation. However, preliminary studies indicate that there could be potential for direct use in drying fish, aquaculture heating, desalination and space cooling at several sites close to large populations centres. Such sites include Abhe, Allol and Sakalol (northeast of Asal) and Gaggadé to the east (Moussa and Souleiman, 2015).

The main technical barriers to geothermal development in Djibouti include extreme salinity of the reservoir fluids, cold seawater incursion into the reservoir, and extremely hot weather conditions. The salinity of the geothermal reservoir in the greater Asal geothermal field exceeds 37 grams per litre (g/L), which presents challenges of aggressive scaling during flashing (Moussa and Souleiman, 2015).

The hot weather can pose problems for power plants, since high air temperatures significantly lower their efficiency. A major resource challenge is the incursion of cold seawater into the geothermal reservoirs associated with tectonism and crustal spreading of the Red Sea divergence centre (Varet, 2014).

Furthermore, non-technical barriers to geothermal development in Djibouti are mainly linked to limited human, financial, legal and institutional capacities. Lack of adequate finance to undertake exploration drilling has contributed to the slow development of the projects. However, the country has recently received funding from various climate and development funds to accelerate geothermal development. Based on the online survey launched by GRMF for an early market engagement in 2019, ODDEG is considering applying for GRMF grants for three surface studies and three drilling programmes to close the funding gap and expand the geothermal development programme in the country. In addition, technical assistance and training are required to support drilling supervision, prevention and control of well scaling, as well as geoscientific studies.

Ethiopia

Ethiopia has grid-connected electricity capacity of about 4 525 MWe from hydropower, wind, bioenergy, solid municipal waste, solar, geothermal and fossil fuel-based generators. The installed electricity trend from 2010 to 2019 shows a steady increase in installed capacity between 2010 and 2016 from around 2 020 MWe to about 2 715 MWe, dominated by hydropower. In 2017, the country more than doubled the installed capacity from 2010 when the capacity increased to 4 435 MWe (Figure 24).

In 2019, renewable energy sources accounted for about 98% of installed capacity in Ethiopia. Among renewable energy sources, hydropower accounted for about 84%; wind, 7%; and bioenergy and municipal waste, 6% each. In addition to grid-connected electricity, Ethiopia derived about 29.3 MWe of electricity from off-grid solutions consisting of bioenergy (17 MWe), solar (11 MWe), hydropower (1.3 MWe) and wind (0.01 MWe).

The addition of wind installations made a large contribution to the increase in installed capacity over the period 2010-2019. A significant increase in hydropower generation in 2017 was due to the commissioning of the 1 870 MWe Gibe III hydropower plant.

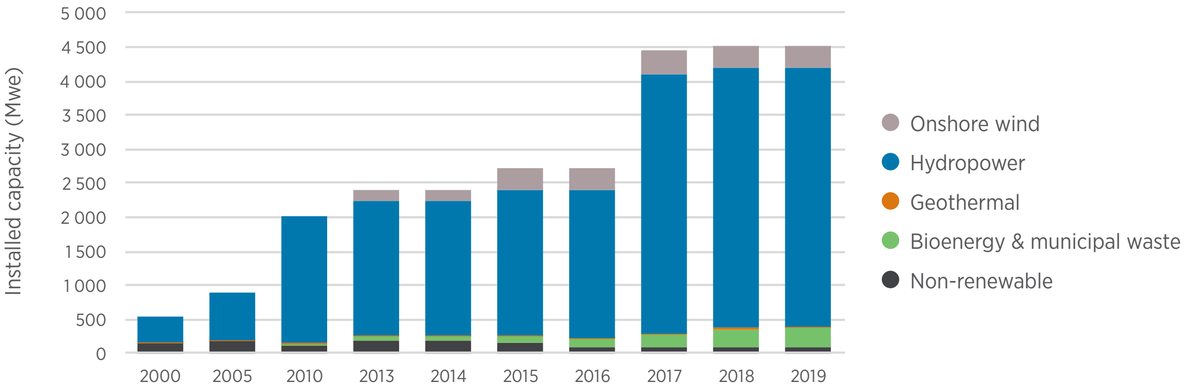
Ethiopia had a very low national electricity access rate of 13% in 2010, but significant growth saw the average national access rate reach 44% in 2017 (Figure 25). Before 2005, electricity was mainly provided to the urban population, which had an electrification rate of 85%, while rural areas had nearly zero electricity connectivity. However, significant growth in rural connectivity was recorded with an electrification rate of 30% in 2017, while the access rate for the urban population increased to 96%.

Ethiopia is one of the countries in the East African Rift with significant geothermal potential. The most prospective sites are located within the Main Ethiopian Rift (MER).

The reconnaissance survey by the Geological Survey of Ethiopia (GSE) started in 1970. Over time, the survey revealed that there are at least 120 hydrothermal sites in the rift valley, of which 24 could be high-enthalpy resources suitable for power generation and direct use (Kebede and Woldemariam, 2018). Among the important prospects from south to north are Abaya, Corbetti, Abiata, Aluto, Butajira, Tulu Moye, Gedemsa, Boku, Boseti, Kone, Fantale, Dofan, Arabi, Meteka, Teo, Danab, Damali, Tendaho, Boina and Dallol (Figure 26).

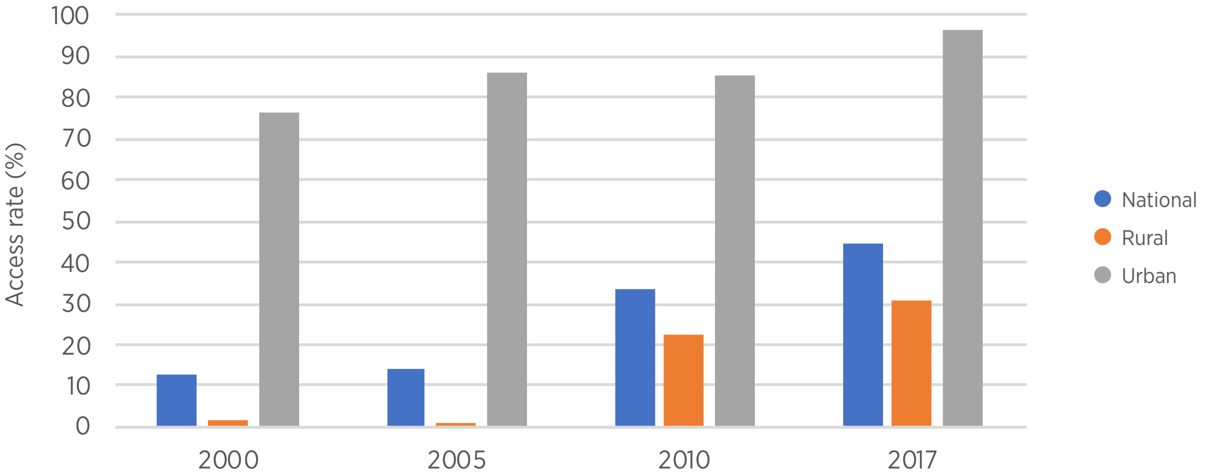
Exploration of the geothermal resources in Ethiopia began in the 1970s. Detailed exploration studies commenced in the so-called Lakes Region, which led to the siting and drilling of exploration wells at the Aluto-Langano geothermal area. Successful drilling in Aluto-Langano resulted in the development of an 8.5 MWe (7.3 MWe net) pilot power plant in 1998. However, the plant operated only intermittently between 2003 and 2015 due to maintenance challenges. The plant has not been operational since 2015.

Figure 24: Grid-connected installed electricity capacity trends in Ethiopia by source



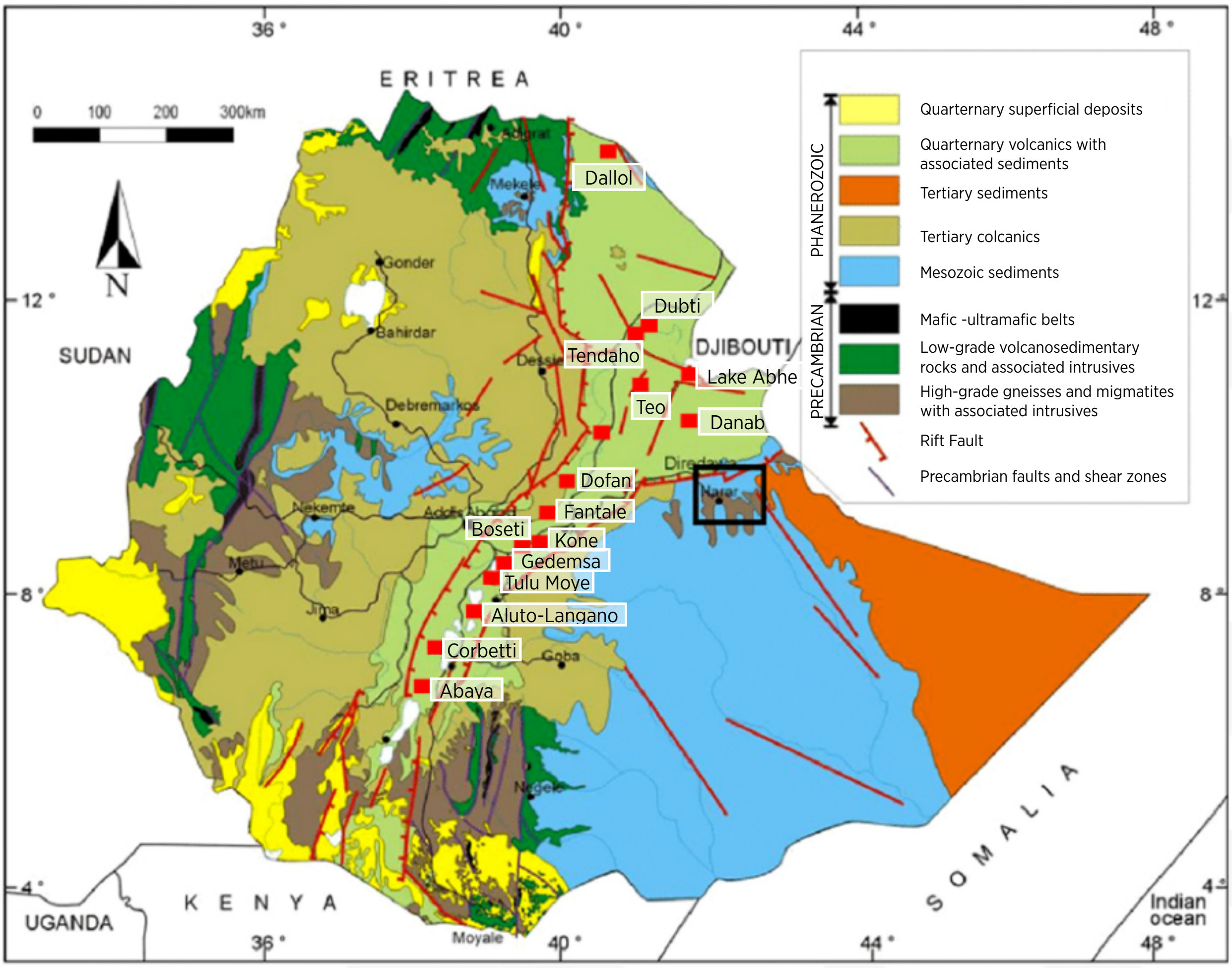
Based on: IRENA (2020a)

Figure 25: National, urban and rural electricity access trends in Ethiopia



Based on: UNStats (2019)

Figure 26. Map of geothermal sites in Ethiopia



Source: Kebede (2012), Geological Survey of Ethiopia (2019)

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

Photograph 1: Aluto-Langano geothermal power plant

Photo credit: Dr. Peter Omenda

With funding from JICA, the World Bank, the Scaling up Renewable Energy Program in Low Income Countries (SREP), and the government of Ethiopia, Ethiopian Electric Power (EEP) plans to rehabilitate the plant and expand the project to 70 MWe (Kebede and Woldemariam, 2018). As part of the expansion of the Aluto project, EEP has acquired a new drilling rig to drill 22 production and re-injection wells at the project site and engaged a drilling contractor for the project.[4] EEP further plans to install 5 MWe modular generators to use steam from appraisal wells LA-9D and LA-10-D, which were drilled in 2013-2014. In March 2020, EEP signed an engineering, procurement and construction (EPC) contract for the development of the small-scale power plant, which is financed by JICA and expected to be commissioned in 2021 (Alhaji, 2020).

Between the 1970s and 2014, all geothermal prospects in Ethiopia were under exploration and development by the government through the GSE and EEP. Whereas this fully public model helped obtain baseline data from all the prospects, it contributed to the slow growth of the geothermal sector due to limited funds available for the geothermal power projects. Besides, the government prioritised hydropower for funding and development.

Between 1993 and 1998, six geothermal wells were drilled in Tendaho geothermal field that proved the existence of viable geothermal reservoirs. The three deep exploratory wells (2100 m) recorded a maximum temperature of 270°C but were unproductive due to low permeability. The shallow wells were productive with reservoir

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[4] Written communication to IRENA by New Zealand Africa Geothermal Facility (January 2020).

temperatures of over 250°C. Prefeasibility studies indicate that the shallow and deep reservoirs can be used for power generation with an estimate of 125 MWe (Kebede and Woldemariam, 2018). In the Afar Region of Ethiopia (*i.e.*, the northern part of the Ethiopia Rift), development of geothermal resources could greatly benefit the country through grid stability. Several geothermal sites have been identified in North Afar by Afar Geothermal Alternative Power Share Company (AGAP), a community-based geothermal company that plans to develop the identified geothermal resource in partnership with interested investors (Nebro *et al.*, 2016; Gardo and Varet, 2018).

Whilst Aluto and Tendaho are publicly developed fields through EEP, in 2014 the government opened the sector to private investment, and four private companies were awarded licenses to explore and develop geothermal resources. Corbetti Geothermal project and Tulu Moye Geothermal project are the most advanced private projects, having completed detailed surface studies. The key to the recent acceleration of the two projects has been the signing of power purchase agreements (PPAs) for the supply of 150 MWe each at a total investment cost of USD 1.6 billion. In March 2020, Kenya Electricity Generating Company PLC (KenGen) started to drill exploration wells in Tulu Moye. Ormat is in the final stages of negotiating a PPA with Ethiopian authorities for the generation of 200 MWe.

The other prospects under private development are Fantale and Butajira (Cluff Geothermal), Abaya (Reykjavik Geothermal), and Wondo Genet, Boku, and Daguna Fango (OrPower 12, Inc.). These prospects have been explored in detail and drilling sites identified for exploration wells. Financing of the projects has come from owners' equity and grants from AUCGRMF (Abdallah, 2018).

Besides the traditional, artisanal use of geothermal in Afar and MER for domestic water production through steam condensation (Nebro *et al.*, 2016), Ethiopia has a recorded history of utilising geothermal resources dating to about 1880, when they were used mainly for bathing by royalty. These hot springs are still in use today with a bathing facility open to the public at Filowha in Addis Ababa. Further recorded utilisation is at the National Palace hotels (Ghion, Sheraton and Hilton) and some schools (Teklemariam and Beyene, 2005). In spite of the low level of utilisation, the country has a large potential for direct use for industrial applications, greenhouse heating, bathing and aquaculture, among others. Utilisation of low-temperature resources for direct use in Ethiopia is expected to see rapid growth with the enactment of the geothermal law as well as the regulations that will promote the development of these resources by communities, regional governments and the private sector (Federal Democratic Republic of Ethiopia, 2016).

Besides the challenge of financing the surface studies and exploration drilling, the other major obstacles that hindered geothermal development for electricity production in Ethiopia were the lack of experience to carry out PPA negotiations with private developers, the lack of a dedicated regulatory framework and limited technical capacity for the geothermal projects. Some of these have since been addressed, but inadequate funding for surface studies and exploration drilling as well as the need to develop an adequate local workforce to undertake all aspects related to geothermal exploration and development are still outstanding.

An additional barrier is a lack of specialised equipment for geothermal development; however, some equipment such as drilling rigs are under procurement by EEP for drilling at Aluto. Despite these challenges, remarkable progress has been made on the ground. For instance, among several projects funded partially by GRMF, the Tulu Moye project exploration drilling began in March 2020, providing optimism for further geothermal project development in the country.

Photograph 2: Geothermal drilling in Tulu Moye

Photo credit: Svarmi Drone Mapping and Survey for TMGO©2020

For direct use applications, the first obstacle is the lack of diffusion of appropriate technologies and experience in shallow drilling in convective systems, particularly for temperatures above 100°C as was found at the shallow ground in Afar Regional State and along the axis of the MER. There is also a lack of specific geoscientific studies to produce three-dimensional modelling of shallow geothermal convective systems.

The main challenge is social, however, as the concerned population (generally pastoralist) is rarely aware of the possibilities of geothermal resource to offer better solutions when captured below the surface. A lack of proper co-ordination of the relevant stakeholders at the local level is a challenge that AGAP is trying to resolve with the support of the Afar Regional State.

Private investors have signed PPAs and completed detailed surface studies for geothermal projects in Ethiopia worth about USD 1.6 billion.

Kenya

Petroleum and electricity are the main modern sources of energy in Kenya. However, energy needs in rural areas and informal urban settlements are provided by wood fuel. Biomass, including wood fuel, contributes about 68% of the total energy consumed in Kenya, with petroleum contributing about 22% and electricity 9% (LCPDP, 2018).

The installed capacity connected to the grid in Kenya as of 2019 was about 2 850 MWe. Of this, geothermal contributed about 823 MWe (IRENA, 2020a) (also see Table 2). Significant growth in installed electricity capacity from renewables was recorded between 2014 and 2019, driven by growth in geothermal, wind and solar installations (Figure 27). During this period, installed capacity for hydropower remained nearly constant. Non-renewable installed capacity increased between 2010 and 2015 but declined between 2016 and 2019.

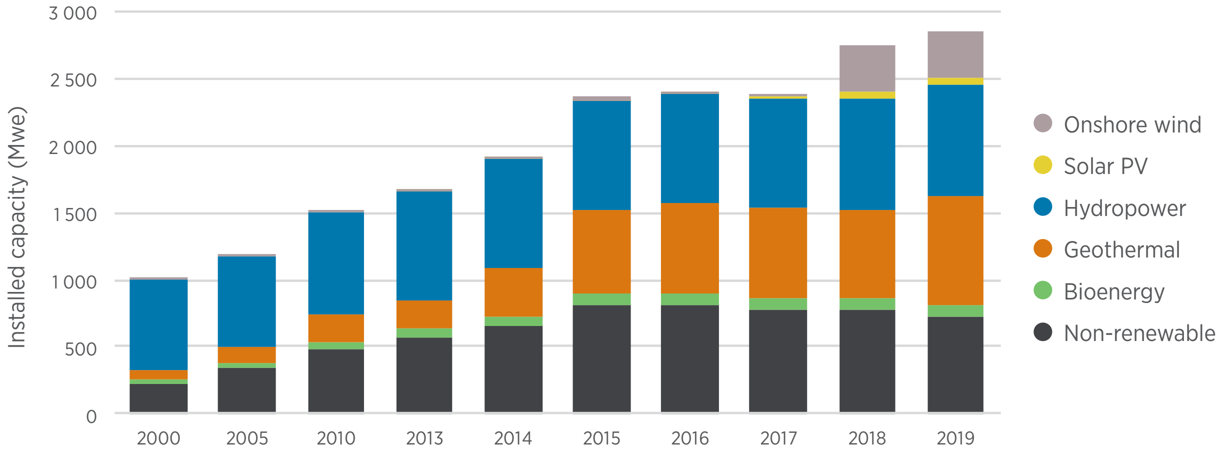
Renewable energy sources contributed about 75% of the total grid-connected installed electricity capacity in 2019. Geothermal and hydropower were the main sources, each with a 29% share of total installed capacity.

Furthermore, Kenya had an off-grid installed capacity amounting to about 75 MWe comprising solar PV (38 MWe), thermal energy sources (30 MWe), hydropower (6 MWe) and wind (1 MWe).

Electricity generation was mainly by hydropower between 2000 and 2014, but geothermal became the foremost source of power consumed in Kenya thereafter. In 2017, the share of electricity generated from geothermal was 46%, hydropower 31%, thermal 21%, and wind 1%. In total, renewable sources of energy contributed about 79% of the electricity consumed in Kenya in 2017.

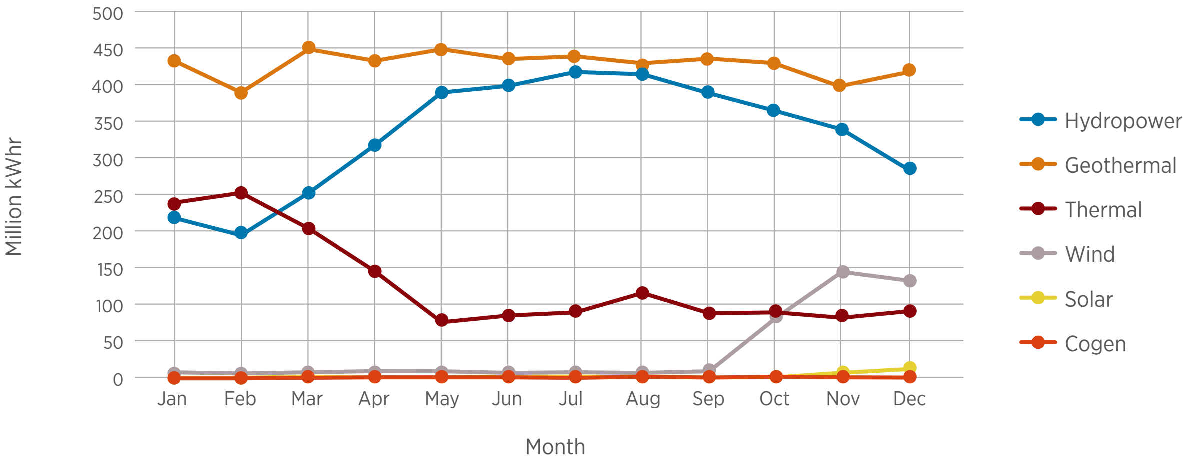
Monthly electricity generation for January December 2018 shows a trend that mimics the weather patterns. While hydropower generation shows significant reduction during the dry months of December to March, thermal generation shows an upswing to cover for the hydropower shortfall during the same season (KNBS, 2019). Geothermal generally shows a flat pattern due to its baseload nature (Figure 28). On the other hand, the increase in wind generation is due to gradual and sequential commissioning of the 300 MWe wind turbines from September 2018.

Figure 27: Grid-connected installed electricity capacity trends in Kenya by source



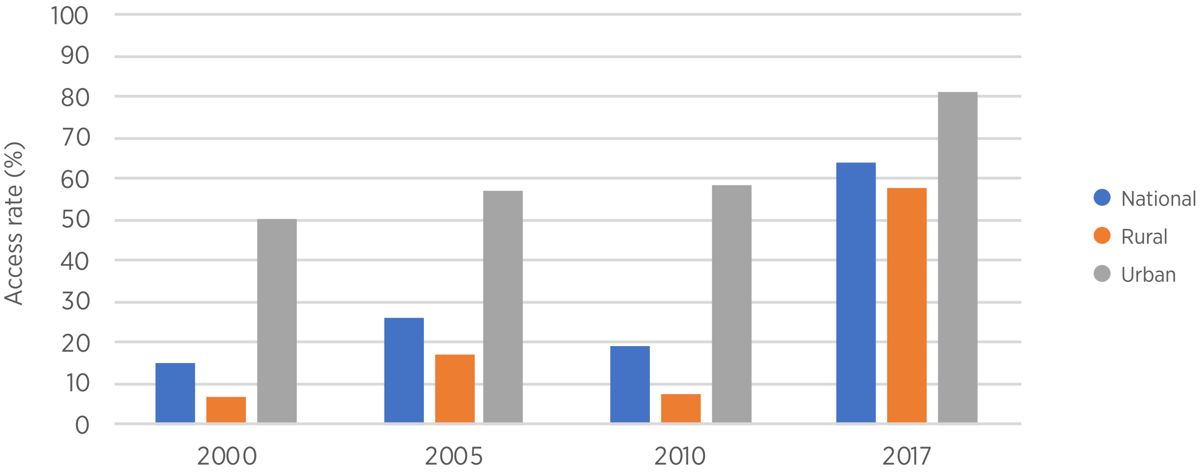
Based on: IRENA (2020a)

Figure 28: Monthly electricity generation/consumption trends in Kenya by source (2018)



Source: KNBS (2019)

Figure 29: National, urban and rural electricity access trends in Kenya



Based on: UNStats (2019)

The electricity access rate in the country stood at about 63% as of 2017, with an urban electrification rate of 81% and a rural electrification rate of 57%. This was a major change from 2010, when the average electrification rate at national level was just 20% (Figure 29).

Kenya's geothermal prospects are mainly located along the Kenya Rift, which is a part of the EARS. The geothermal prospects that correspond to volcanic centres in Kenya are: Suswa, Longonot, Olkaria, Eburru, Menengai, Korosi, Paka, Silali, Emuruangogolak, Barrier, and Homa Hills. Other geothermal prospects, which are not associated with central volcanoes, include Namarunu, Lake Baringo, Lake Bogoria, Lake Magadi, and the Elementaita and Akiira geothermal areas. Some geothermal prospects, such as Mwananyamala and Homa Hills, lie outside of the Kenya Rift valley (Figure 30).

Geothermal exploration for power development in Kenya started in the 1950s with geological investigations in the region between Olkaria and Lake Bogoria. The exploration with funding support from UNDP resulted in the drilling of two deep wells in Olkaria in 1956 (KPLC, 1992). Subsequent exploration drilling was undertaken in Eburru in the 1990s, Menengai in 2011 and the Baringo-Silali Geothermal Block in 2019. In Olkaria, the development was undertaken in phases where the field was subdivided into seven exploration blocks. Exploration work in Olkaria 1 resulted in drilling of six wells between 1973 and 1976, which confirmed the presence of a geothermal resource. Since then, several power projects have been developed in the Olkaria field, as shown in Table 2.

Geothermal development stagnated from 1985 to 2000 (Figure 31) before the current rapid growth started. All the KenGen-owned geothermal developments at Olkaria and Eburru (totalling 706 MWe) were funded directly by the government of Kenya and through concessionary funds guaranteed by the government.

Figure 30: Map of geothermal sites in Kenya

Source: Geothermal Development Company (GDC) Library

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

Table 2: Installed geothermal power plants and conversion technology (2019)

Power plant	Ownership	Year commissioned	Technology	Installed capacity (MWe)
Olkaria I	KenGen	1982-1985	Flash	45
Olkaria I (AU)	KenGen	2016	Flash	150
Olkaria II	KenGen	2003 and 2009	Flash	105
Olkaria III	OrPower 4 Inc.	2000-2018	Binary ORC	170
Olkaria IV	KenGen	2014	Flash	150
Olkaria V	KenGen	Aug. 2019	Flash	172.3
Olkaria Wellheads	KenGen	2010-2016	Flash	81.1
Oserian	Oserian Development Company	2006	Flash (Back pressure) and Binary- ORC	3.6
Eburru wellhead	KenGen	2012	Flash	2.52
Total (in operation in 2019)				**880**[5]
Olkaria I Unit 6	KenGen	Expected 2020	Flash	83
Olkaria PPP	KenGen	Expected 2021	Flash	140
Menengai Units 13	IPPs	Expected 2020/21	Flash	105
Under development				**328**

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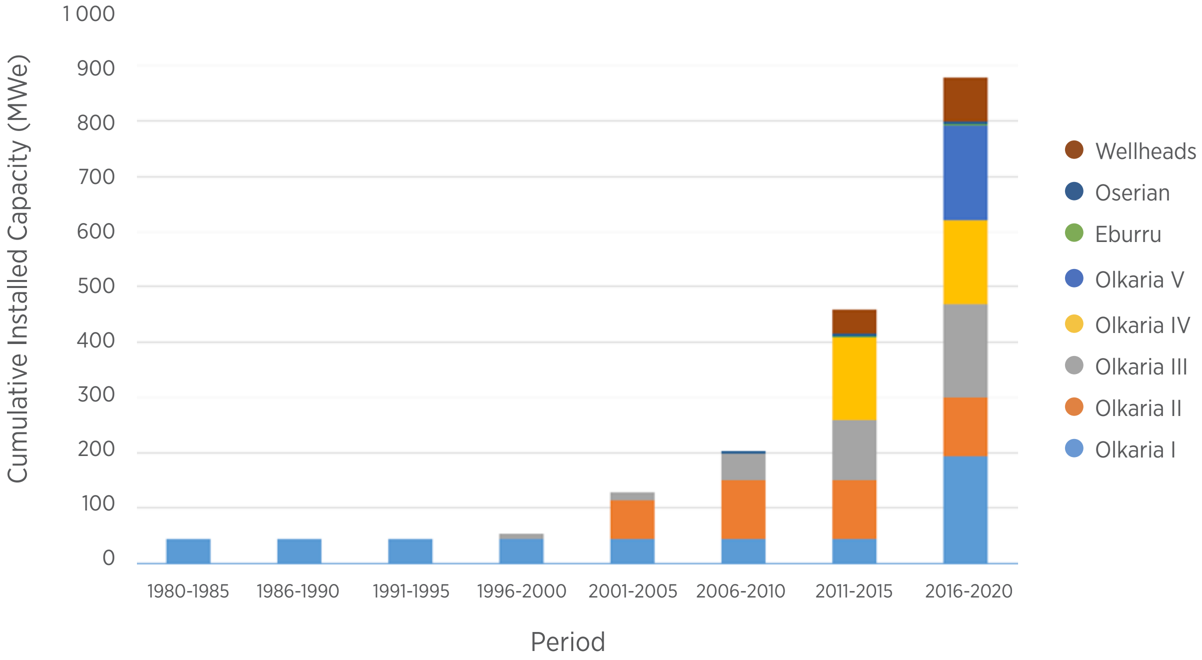
[5] The 880 MWe installed capacity in operation in Kenya refers to the gross power (MWe) generated, as indicated on the name plate of the turbines, and includes the 3.6 MWe captive power by Oserian flower farm for private use. This differs from the 823 MWe reported in the official IRENA statistics (Figure 7), which refers to the actual power received by the local power utility from the generators and sold to the market.

Olkaria III power project was the first geothermal project in Kenya involving the private sector. In 2000, the government of Kenya entered into an agreement with OrPower 4 Inc. after having drilled six wells state resources. The project currently has an installed capacity of 170 MWe of ORC technology.

Using wells drilled in the Olkaria fields, Oserian Development Company (Oserian flower farm) constructed two power plants with an installed capacity of 2.4 MWe and 1.2 MWe of ORC and backpressure technologies, respectively. The first power plant was commissioned in 2004 and the second in 2006 to generate power for internal use in the farm. In Eburru, a 2.52 MWe well head power plant was commissioned in 2012 using an existing well with a temperature >285°C (Omenda and Simiyu, 2015). KenGen plans to expand the power plant in stages.

In Menengai, appraisal and production drilling have confirmed steam equivalent of more than 170 MWe, and drilling is continuing in the field (Box 2). Development of the power plants has however experienced delays due to the complexity in implementing the PPP model adopted. This has resulted in a prolonged process to close the Conditions Precedent (CPs) set out in the Project Implementation and Steam Sale Agreement (PISSA), PPA and requirement by the IPP lenders to enable the IPPs to reach financial close. Geothermal power plants with a total installed capacity of 105 MWe are expected to be developed in Menengai by three IPPs, with the first unit of 35 MWe expected to be commissioned by 2021.

Figure 31: Cumulative geothermal installed capacity trends for Kenya



Box 2: Establishment of the Geothermal Development Company

The Geothermal Development Company (GDC) is a government-owned company that was incorporated in 2008 to accelerate the development of geothermal resources in Kenya. It was mandated to undertake geothermal resource assessment, manage the proven steam fields and sell steam to geothermal power plant operators. GDC is therefore mandated to carry out geothermal exploration (including surface studies and exploration drilling) to minimise the early stage risk associated with geothermal projects, drill appraisal and production wells, manage the steam fields in its licensed areas and enter into steam sales agreements with investors. GDC also builds capacity for geothermal development through training of its staff and acquisition of various equipment necessary for geothermal development and promotes the development of direct uses of geothermal energy.

Funding for GDC's operations come from the exchequer, development partners as grants or concessional loans guaranteed by the state, and revenue derived from the sale of steam to the power plants. Since 2008, GDC has raised over USD 800 million for the procurement of seven drilling rigs, workshop tools and scientific equipment, and the cost of drilling more than 90 wells at Olkaria, Menengai and Paka geothermal fields.

Photograph 3: Discharging geothermal well in Menengai geothermal field

Photo credit: GDC

Following the aspirational goal of the Kenyan government to generate 5 000 MWe of electricity from all sources by 2030, GDC developed a programme to realise about 1 000 MWe steam equivalent by 2030 from three of its licensed fields in Kenya with the support of development partners through grants, loans and technical assistance (TA) programmes. Since its inception in 2008, GDC has developed Menengai and Paka fields from greenfields to the production and appraisal drilling status, respectively, and undertaken detailed field studies at Korosi, Silali and Suswa, among other fields. As of December 2019, GDC's operations in Olkaria had resulted in the development of over 400 MWe of steam equivalent, of which 320 MWe equivalent of steam is sold to KenGen via a steam sale agreement to generate electricity for the grid. In Menengai, over 170 MWe of steam equivalent has been developed and steam sale agreements signed with IPPs for the generation of 105 MWe (GDC, 2017a). The GDC model has also been adopted in Tanzania with the establishment of Tanzania Geothermal Development Company Ltd (TGDC) and in Djibouti with the formation of ODDEG.

In the Baringo-Silali geothermal block, detailed exploration studies have been conducted in the area, which comprises several geothermal fields: Baringo, Chepchuk, Korosi, Paka and Silali. With funding from KfW and the government of Kenya, GDC is developing infrastructure in Korosi, Paka and Silali to facilitate drilling of 20 wells.

In 2019, two geothermal wells funded by the government and GRMF were successfully drilled in Paka, proving the presence of a geothermal resource in the field. GDC may subsequently drill the fields to full steam status including production drilling or invite private investors to join at production drilling stages and power plant development. Drilling at Korosi and Silali prospects, which are also partially funded by GRMF, was planned to start in 2020.

As for direct use, geothermal heat has been used in Kenya for bathing, crop drying, aquaculture and greenhouse heating. The first recorded direct use application in Kenya was the pyrethrum dryer built in 1939 in Eburru for use in drying pyrethrum flowers and cereals.

The dryer is still operational to date with minimal maintenance requirements. The largest direct use facility is at Oserian Development Company Limited, a company which operates the world's largest geothermal heated greenhouse for growing rose flowers. Oserian heats its greenhouses to regulate humidity at night and during the wet season, thereby minimising incidences fungal diseases. The geothermally heated greenhouse project at Oserian covers 50 hectares. The project uses hot water from a well leased from KenGen known to have cyclic characteristics (Melaku, Thompson and Mills, 1995; Knight, Hole and Mills, 2006).

The greenhouse system at Oserian uses a heat exchanger to heat freshwater to about 80°C (Melaku, Thompson and Mills, 1995). In addition, water for fertigation purposes is sterilised using geothermal energy before it is fed to the flowers to minimise the occurrence of diseases.

Besides heating, Oserian runs a programme of carbon dioxide enrichment to enhance photosynthesis whereby the carbon dioxide concentration in the greenhouse is raised by adding the carbon dioxide from the geothermal resource (Mburu, 2014).

Photograph 4: Oserian geothermal heated greenhouse

Photo credit: Dr. Peter Omenda

A commercial spa has been developed by KenGen at Olkaria II geothermal field. The spa utilises brine meant for re-injection in the field (Mangi, 2013). Three hot water pools/lagoons receive hot brine sequentially from the source. The brine flows into the first lagoon at about 91°C, into the second lagoon at about 85°C and into the third lagoon at about 69°C. The main and largest lagoon is maintained at a temperature of 30°C-35°C. KenGen has also set up a sauna and steam bath (Table 3). In addition, Lake Bogoria Spa and Hotel operates a swimming pool that utilises water from a nearby hot spring.

Furthermore, GDC developed a demonstration facility in Menengai geothermal field to showcase the technical and financial viability of direct use. The facility consists of a geothermal-heated greenhouse, geothermal-powered laundry operations, aquaculture pond heating, geothermal milk pasteurisation and geothermal grain dyer.

A heat exchanger is used to extract thermal energy from a low-pressure well which is not suitable for electricity generation. Thermal energy is transferred from the geothermal fluid into fresh water, which is heated to about 82°C. The heated fresh water is then used to regulate the temperature in the greenhouse at night, early morning and during wet seasons to control relative humidity depending on the requirement of the crops in the greenhouse, reducing the occurrence of fungal infections.

The temperature of two ponds for rearing fish is maintained at 29°C, which is the optimal temperature for tilapia, by running the heated water through the pond to regulate the temperature. At a temperature of around 80°C, the heated water is used to pasteurise fresh milk through batch processing.

The geothermal laundry in the Menengai facility uses the hot water for washing as well as for drying cloth (Nyambura, 2016). The grain dryer installed in Menengai was tested in November 2019.

Table 3: Direct use installed capacity and energy use in Kenya

Use	Installed capacity (MWt)	Annual energy use (TJ/yr = 10^{12} J/yr)
Greenhouse heating	5.3	185
Agricultural drying	0.3	9.9
Fish farming	0.2	6.5
Bathing and swimming	8.7	275.5
Other uses (laundry operations and milk pasteurisation)	4	125
Total	**18.5**	**602.4**

Note: MWt = megawatt thermal; TJ = terajoules; yr = year; J = joules.
Source: Lund and Toth (2020)

Photograph 5: Menengai direct use project: Milk pasteuriser (left) and grain dryer (right)

Photo credit: GDC

The United States Agency for International Development (USAID) supported GDC to undertake prefeasibility studies for potential direct use applications in Kenya that included milk pasteurisation, drying of crops, greenhouse heating, aquaculture heating and use of geothermal energy in abattoir processes through a technical assistance initiative (USAID, 2013a; USAID, 2013b; USAID, 2013c).

Results of the studies indicated the existence of a potential market for direct use as well as potential savings on energy for some agro-industrial thermal processes if geothermal energy is used in place of fossil fuels, assuming that the energy for direct use is obtained from existing geothermal wells drilled for electricity generation.

The successful geothermal story of Kenya can be attributed, amongst other aspects, to strong government support (political and financial) and a well-developed human capacity for geothermal exploration and development.

Geothermal will continue to be the leading source of power consumed in the country in the coming years. However, the rate of growth in geothermal power development is expected to decrease due to the current mismatch of electricity supply and demand in the country, where supply has grown at a higher rate than demand. As of July 2019, Kenya was reported to have an electricity grid installed capacity of 2732 MWe against a peak demand of 1870 MWe (Kamau, 2019). This means that the reserve capacity is 46% of the peak demand, resulting in financial constraints to the off-taker. As a consequence, the off-taker, Kenya Power and Lighting Co. Ltd, froze signing of new power purchase agreements in 2019, locking out 23 applications with a combined capacity of 2240 MWe which were under consideration. However, this oversupply is expected to ease as the government in 2018 initiated the Kenya National Electrification Strategy (KNES) in a push to achieve access to electricity for all in the country by 2022. This is in addition to the Last Mile Connectivity Programme and Slum Electrification Program, which supported the growth of access to electricity in Kenya to the current level of 63% nationally (World Bank, 2018).

Furthermore, the government of Kenya indicated its intention to disconnect three fossil-fuelled power plants by 2020 with a total installed capacity of 190 MWe from the national grid (Ngugi, 2019). At a regional level, the development of power interconnectors through the power pools will facilitate the exchange of electricity with other countries, further easing the burden of oversupply.

An absence of clear licensing procedures, regulations and incentives have hampered the development of direct use projects. The Energy Act 2019 only mentions that regulations will be developed by the Renewable Energy Resource Advisory Committee (RERAC).

Up to now, the direct use projects in Kenya were developed as spin-offs of electricity production projects, except the project in Eburru. The future challenge for Kenya – as well as other countries in the EARS – is to be able to develop conditions that would allow local entities – city, village, county, cooperative or any kind of appropriate community-based organisation – to take the lead in developing direct use of geothermal resources.

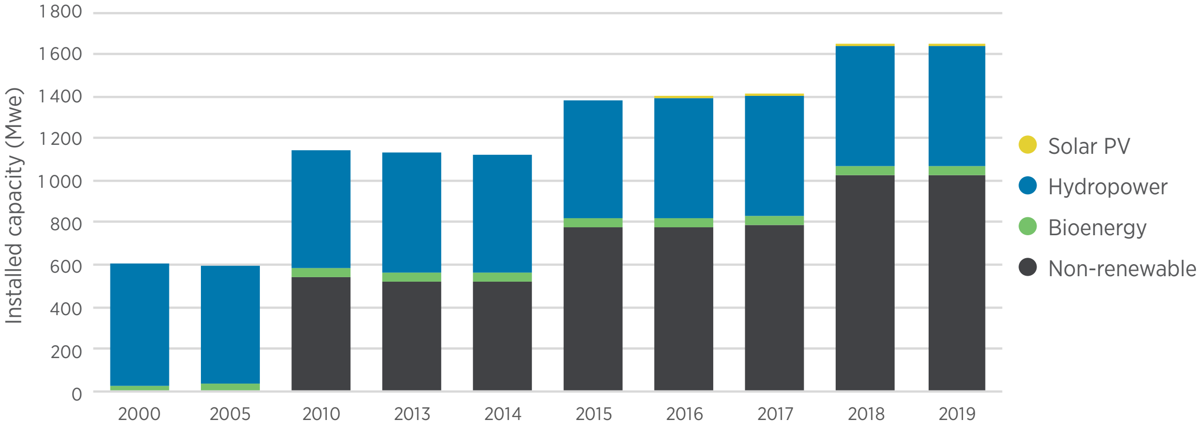
Tanzania

Tanzania has seen slow growth in its grid installed electricity capacity, with expansion from about 1150 MWe in 2010 to 1640 MWe in 2018.

Hydropower was the main source of electricity between 2010 and 2014, with an installed capacity of about 570 MWe. An accelerated growth in fossil fuel-based generation was recorded from 2015 to 2019, however. During this period, the installed capacity from fossil fuels increased from 520 MWe in 2014 to 1028 MWe in 2019 (Figure 32). The growth in installed capacity from fossil-fuel power plants in 2015 is attributed to expanded capacity to utilise natural gas extracted from the Rufiji basin of eastern Tanzania.

In addition, the country has an off-grid installed capacity of 120 MWe consisting of non-renewables (53 MWe), bioenergy (26 MWe), hydropower (15 MWe) and solar PV (26 MWe).

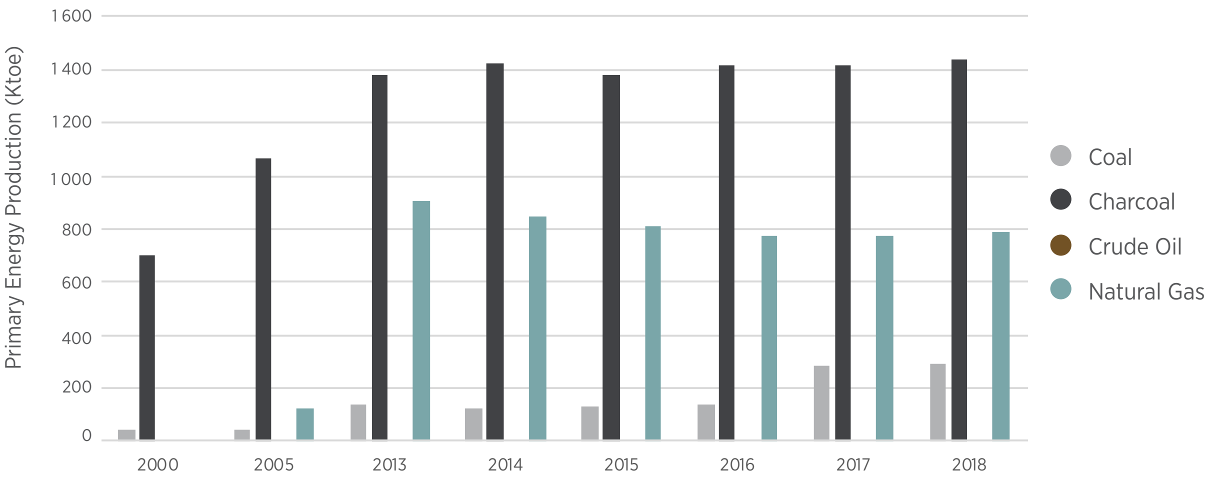
Figure 32: Grid-connected electricity installed capacity trends in Tanzania by source



Based on: IRENA (2020a)

As depicted in Figure 33, domestic fuel production in Tanzania consisted of coal, charcoal and natural gas. In particular, extraction of natural gas started in 2005 at 127 ktoe with a major increase to 903 ktoe in 2013 (AFREC, 2018).

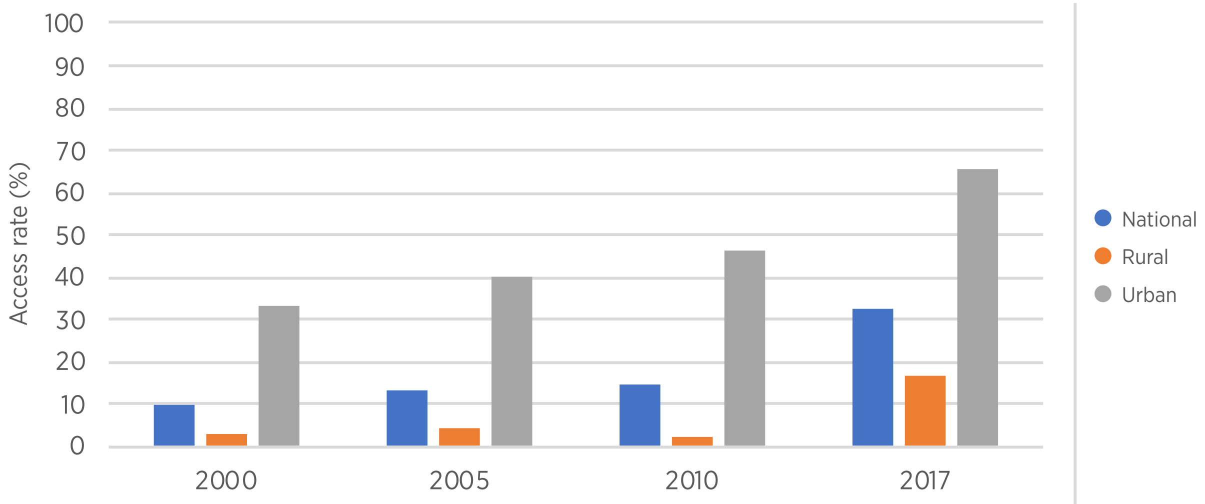
Figure 33: Domestic fuel production trends in Tanzania by source



Based on: AFREC (2018)

The national electricity access rate in Tanzania has remained low, despite an increase from 9% in 2000 to 32% in 2017. The fastest growth in access rates was for urban centres, which increased from 33% in 2000 to 65% in 2017 (Figure 34). However, rural access rates remained some of the lowest in the region (<5%) for the period 2000 to 2010 but increased to 17% in 2017.

Figure 34: National, urban and rural electricity access trends in Tanzania



Based on: UNStats (2019)

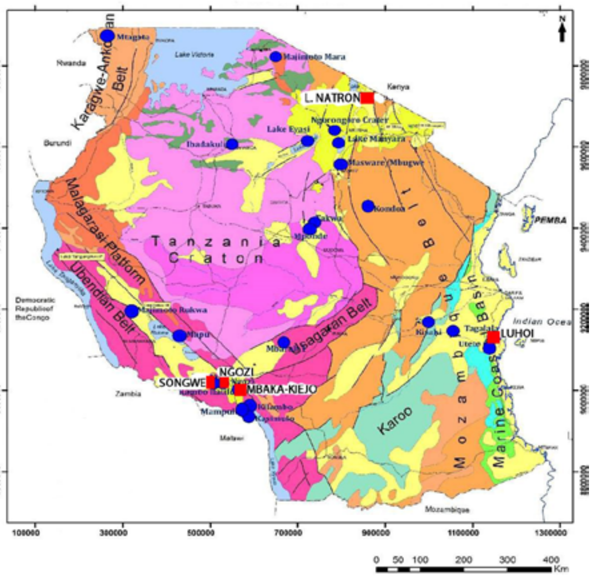
Geothermal resource development in Tanzania is at the exploration stage with reconnaissance and detailed surface studies in the four main areas of interest. These are: the northern volcanic region around Lake Natron; the central region within Tanzanian craton; the southern region around Mbeya; and the eastern region along the coast within the Rufiji basin (Figure 35). Tanzania Geothermal Development Company (TGDC), the state agency in charge of geothermal development, has identified in its strategic plan four projects areas that could contribute to the realisation of the 2025 target of generating 200 MWe from geothermal energy: Ngozi, Songwe, Kiejo-Mbaka and Lake Natron.

Ngozi is currently the flagship geothermal project in the country. Detailed surface studies have been undertaken including geological, geochemistry and geophysical studies, and a conceptual model developed that indicates the possible occurrence of a high-temperature geothermal system. TGDC estimates that the resource could generate more than 45 MWe (TGDC, 2017). TGDC plans to drill two to three exploration slim holes in the Ngozi geothermal prospect down to a depth of 1 000 m to 1 500 m to confirm the existence of a geothermal system with funds from GRMF, SREP and the government of Tanzania.

Kiejo-Mbaka geothermal prospect is located in the southern volcanic region within the Rungwe volcanic field. Detailed studies have been undertaken in the area, and a medium-temperature fracture-controlled geothermal system defined. Thermal gradient holes drilled in the area encountered hot self-discharge fluids at a depth of 70 m. Fluid geothermometry suggests that the reservoir temperatures could reach 160°C-180°C. It is estimated that this resource could support a 15 MWe binary power plant in the first phase of development (TGDC, 2017).

In the Songwe geothermal area, detailed geothermal exploration studies undertaken in the area suggest a medium-temperature, fracture-controlled geothermal system suitable for both binary power generation and direct use. TGDC is planning to drill thermal gradient holes to define the resource upflow zones to aid in the selection of suitable sites for exploration wells. It is estimated that the resource at Songwe could support 20 MWe power project and presents a great opportunity for direct use, including for bathing/balneotherapy and crop drying.

Figure 35: Map of geothermal sites in Tanzania



Source: Kato, Mnjokava and Kajugus (2016)

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

Kibiro, Panyimur and Buranga are at advanced stages of exploration while other Ugandan geothermal areas are at the reconnaissance phase.

The Natron geothermal area is the least studied but has a high potential for power generation and direct use. It has hot springs with a large flow rate (TGDC, 2017). The prospects in the west of the Natron basin are low- to medium-temperature fracture-controlled systems and discharge hot springs at a maximum temperature of 52°C with an estimated reservoir temperature of about 100°C-130°C from fluid geothermometry. Geophysical studies indicate shallow seismic activities associated with Gelai Volcano in the east of the basin. TGDC intends to investigate this area for a possible high-temperature, volcano-hosted geothermal system. Other geothermal areas, including Luhoi and Kisaki in eastern Tanzania and the geothermal areas in the central part of the country, are believed to be low-temperature geothermal systems better suited for direct use applications.

There are currently no commercial-scale direct use applications in Tanzania. However, small-scale application are found in the Arusha and Kilimanjaro areas, Songwe, Mbaka fault, Luhoi and Lake Natron. The main direct use application in these localities is bathing, especially for tourism. The facilities are used in the elementary form with minimal marketing. At Songwe, the main attraction is the beautiful landscape produced by the carbonate springs. The springs produce carbonate sinters which are used as feed supplement for cattle (Mnjokava, Kabaka and Mayalla, 2015). The travertine deposits discharge at temperatures of as high as 79°C. TGDC has made an effort to promote direct use in Tanzania by undertaking prefeasibility studies for Luhoi and Songwe geothermal areas by examining the potential applications.

In terms of barriers slowing geothermal development in Tanzania, as in many countries in the East African Rift region, limited technical skills and inadequate equipment for geothermal exploration and development are the major factors. TGDC and the Tanzanian government are addressing this by training scientists, engineers and technicians. Since TGDC intends to undertake a portfolio of geothermal projects to achieve the planned generation of 200 MWe by 2025, a large number of personnel will be required to manage all the projects.

In addition, most of the geothermal resources in Tanzania are fracture-controlled and not well understood since there are no successfully developed examples of fracture-controlled geothermal systems within EARS. Increased availability of equipment for resource evaluation is required to meet the timelines for the development of the power projects. These include field and laboratory equipment as well as rigs for shallow and deep drilling. TGDC calculates that owning the equipment will fast-track the developments and lower the project cost.

Additionally, there is limited financial availability and a lack of a conducive regulatory and legal framework for private investments, despite the National Energy Policy of 2015 considering private investment as a critical catalyst for rapid growth in the sector. Another reason for slow progress in geothermal development can also be attributed to the growth of gas-fired power plants observed since 2015, primarily due to the discovery and production of natural gas in the Rufiji basin of eastern Tanzania. To some extent, the off-taker risk in Tanzania has also contributed to slow growth as the local utility, TANESCO (Tanzania Electric Supply Company), is considered to have high offtake risk.

TGDC was established as a subsidiary of TANESCO based on the “Kenyan model” of GDC (see Box 2). This was of course a determinant initiative to accelerate the development of geothermal resources in the country. However, given that the main geothermal systems are fault-controlled, low-medium-temperature resources, the service offered by the company has to adapt to these different kinds of projects.

Therefore, a focus on power generation in combination with direct use projects could be considered, taking into account the community living on site and their local economic activities. This means that for such projects to be developed, a socio-anthropological and socio-economic approach need to be developed early in the project through prefeasibility studies, in parallel with the geoscientific approach. This therefore implies the need for a partnership between the local entities and TGDC.

Uganda

The electricity sector in Uganda saw growth, from 630 MWe to 1 179 MWe, in grid installed capacity between 2010 and 2019. The increase in installed capacity was mainly from additional hydropower, solar and bioenergy (Figure 36). Renewables constituted the largest share of grid-connected electricity at 88% in 2019. The installed capacity is primarily hydropower, with a share of 76% in 2019. Bioenergy constituted 7%, while solar PV made up 5%. In addition, Uganda has an off-grid installed capacity of 33 MWe consisting of solar PV (28 MWe) and hydropower (5 MWe).
Although there has been an increase in electricity access in Uganda, the national average is still among the lowest in the region at 22% in 2017, with more than 33 million people unserved (Figure 37). In the period 2000 to 2017, urban connectivity increased from 41% to 57%, while rural connectivity increased from a low of 0.7% in 2005 to 11% in 2017.

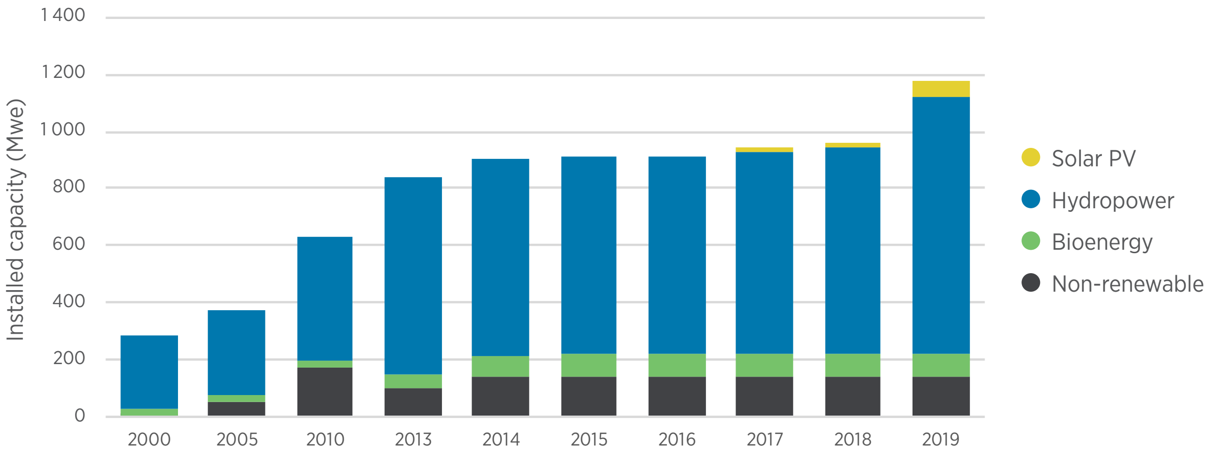
Geothermal resources in Uganda are all located in the Western branch of the EARS, mainly along the Uganda-DRC border.

The main geothermal areas characterised by large hot spring flows are Katwe-Kikorongo (Katwe), Buranga, Kibiro, Panyimur and Ihimbo. Among these, Kibiro, Panyimur and Buranga are at advanced stages of exploration while the others are at detailed reconnaissance phase. The evaluation of the geothermal systems in Uganda revealed that all the systems are fault/fracture-controlled and low to medium temperatures (Omenda *et al.*, 2016a).

New recommendations have been made on appropriate and suitable methods for geothermal exploration in the fault/fracture-controlled systems found in Uganda and most of the Western branch of the EARS (see Chapter 7).

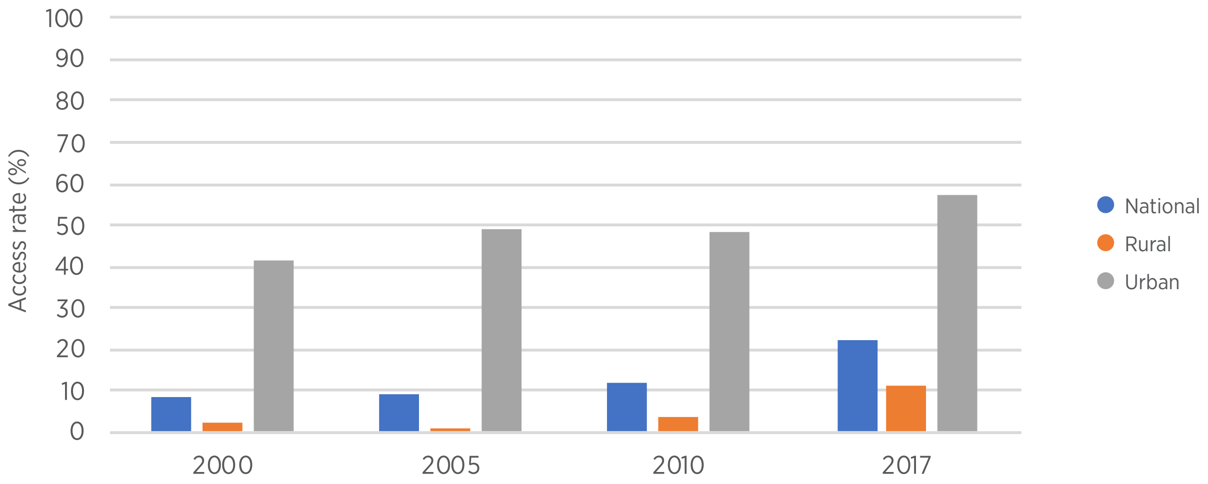
Until the mid-2010s, the prospects were evaluated using techniques suited for volcano-hosted systems as those applied in Kenya and Ethiopia. With the new approach, the Uganda government selected three prospects for active exploration for power and direct use. These include Kibiro, Buranga and Panyimur geothermal prospects, which also qualified for GRMF funding (Figure 38).

Figure 36: Grid-connected installed electricity capacity trends in Uganda by source



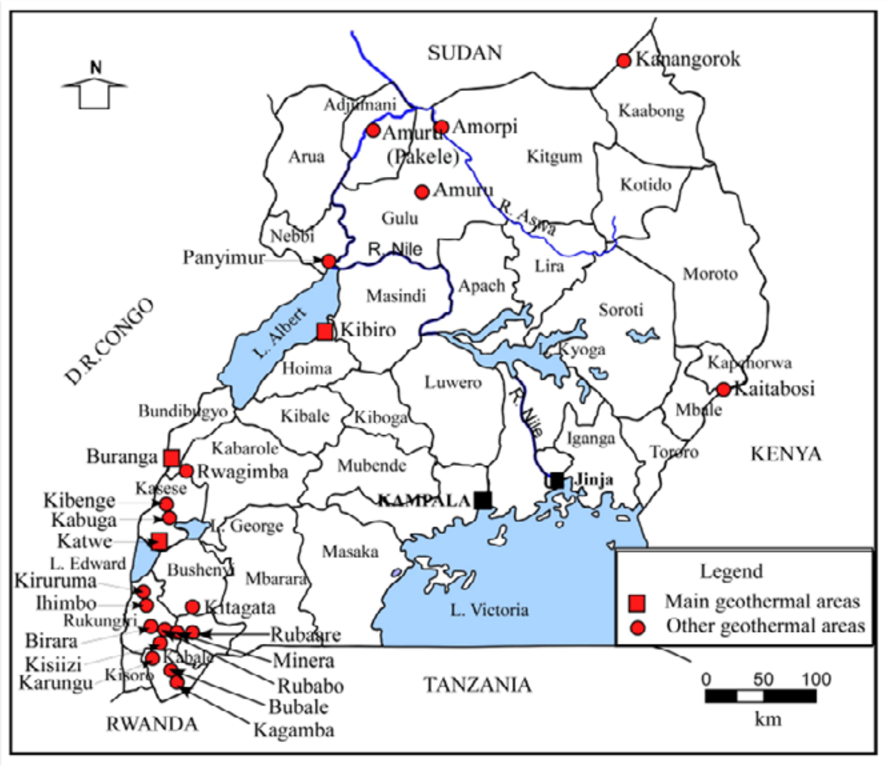
Based on: IRENA (2020a)

Figure 37: National, urban and rural electricity access trends in Uganda



Based on: UNStats (2019)

Figure 38. Map of geothermal sites in Uganda



Source: Bahati *et al.* (2005)

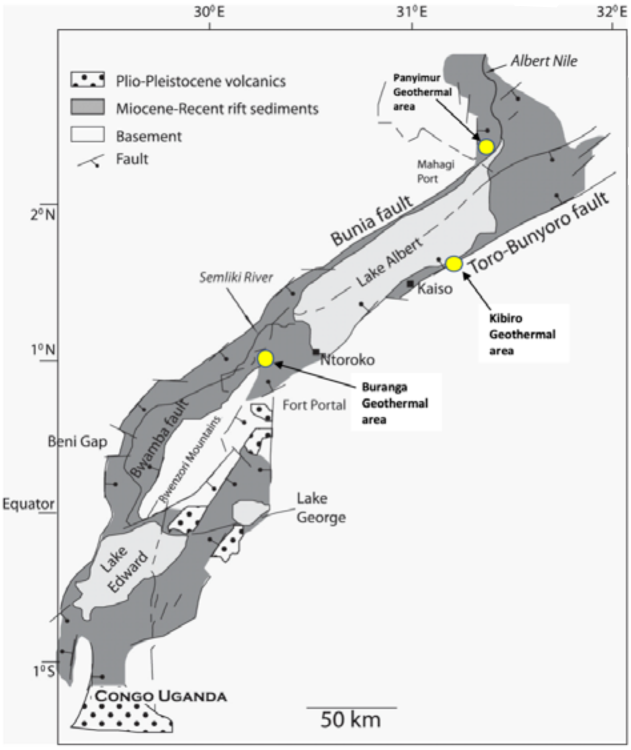
Disclaimer*:* Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

The geothermal system at Kibiro is associated with intersecting fault and fracture systems along which hot hydrothermal fluids upflow.[6] The main structure is the northeast trending and west-dipping Northern Bunyoro Toro fault system with its associated complex step-overs and fault intersections (Bahati and Natukunda, 2018). Conceptual modelling suggests a medium temperature geothermal system located along with the fault system with the potential of up to 15 MWe (Alexander, 2016).

The Kibiro geothermal prospect is under development by the Uganda government. Drilling of temperature gradient holes commenced in the first quarter of 2020 funded by the Ugandan government and the GRMF (GRC, 2019). If successful, the project will be leased to a private developer under PPP arrangement or to the Uganda Electricity Generation Company Limited.

The Buranga geothermal prospect, located in western Uganda, is characterised by hot springs to the northwest of Rwenzori Mountain near the foot of Bwamba escarpment and localised by northeastern trending border faults (Ring, 2008; Natukunda and Bahati, 2018) (Figure 39). Studies undertaken to date have conceptualised a fault/fracture-controlled geothermal system with main upflow at the intersection of northeastern striking, west-dipping rift faults and oblique structures that strike northwest. The Buranga prospect is licensed to Gids Consult Ltd, which intends to drill thermal gradient holes in 2020 that would lead to drilling exploration wells in 2020/2021.

Figure 39: Map of western Uganda showing the location of Kibiro, Buranga and Panyimur prospects



Source: Ring (2014)
Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

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[6] Fracture/fault-controlled geothermal systems are discussed in Chapter 7, Section 3.

The Ugandan section of the western branch of the EARS hosts the Panyimur geothermal prospect (Figure 39), which is characterised by hot springs with a temperature of up to 61°C (Lugaizi *et al*., 2018). It was determined that the hot springs discharge from northeastern striking, east-dipping fault structures associated with the western branch of the EARS. The reservoir is postulated to be associated with the fault damage zone and is modelled as a low- to medium-temperature resource. Also, in the case of the Panyimur project, the Ugandan government, supported by the GRMF, has signed contracts for temperature gradient holes planned for the second quarter of 2020.

In January 2020, drilling of up to eight temperature gradient wells was undertaken in Kibiro. However, a blowout occurred in March resulting in uncontrolled release of gas, drilling fluids, geothermal fluids and sediments. The resulting pollution around the geothermal area necessitated the Ministry of Energy and Mineral Development to halt the drilling activities in all the three geothermal prospects until an environmental and social impact assessment is undertaken (Afrik21, 2020).

A prefeasibility study for combined power and direct use facilities carried out by East Africa Geothermal Energy Facility (EAGER) in 2018 assessed the potential for direct use in Kibiro and Panyimur. At the Kibiro site, a facility combining both salt production from the Kibiro hot springs and fish drying was found to be economically viable. Other viable applications include fingerling hatcheries and aquaculture. As for Panyimur, crop drying and fingerling hatcheries were found to be economical. In addition, greenhouse heating could be economical for high-value crops in Panyimur (EAGER, 2018).

The Kibiro hot springs have total dissolved solids (TDS) of more than 5 000 milligrams (mg)/kilogram (kg), which is dominated by NaCl (sodium chloride) and a total flow of approximately 7 litres per second (L/s) and a temperature of 86°C at the surface. The spring waters flow and soak into the sediments of the Kibiro Basin, depositing the salts within the formation, which is currently harvested for cattle lick.

Since the area is important for cattle rearing, local residents recover salts deposited in the sediments for domestic use and as a mineral supplement for cattle. Other than fishing, this is the other important economic activity for the community living adjacent to the hot springs.

Kitagata hot springs, located in western Uganda, is the most visited hot spring in Uganda. It is used both by the local population and by foreign tourists, who visit the spring for bathing, recreation or balneotherapy.

It is clear that direct use of geothermal resources can create viable economic activities for local communities and the government. The Uganda government is therefore taking a proactive approach by promoting both electricity generation and direct use of geothermal resources through awareness creation and focussed training.

The slow progress in geothermal development in Uganda can be attributed to exploration studies which were based on a model of volcano-hosted geothermal systems; lack of sufficient state-of-the-art field and laboratory equipment for data collection, analyses and modelling; lack of supportive policy; and inadequate incentives for private geothermal development.

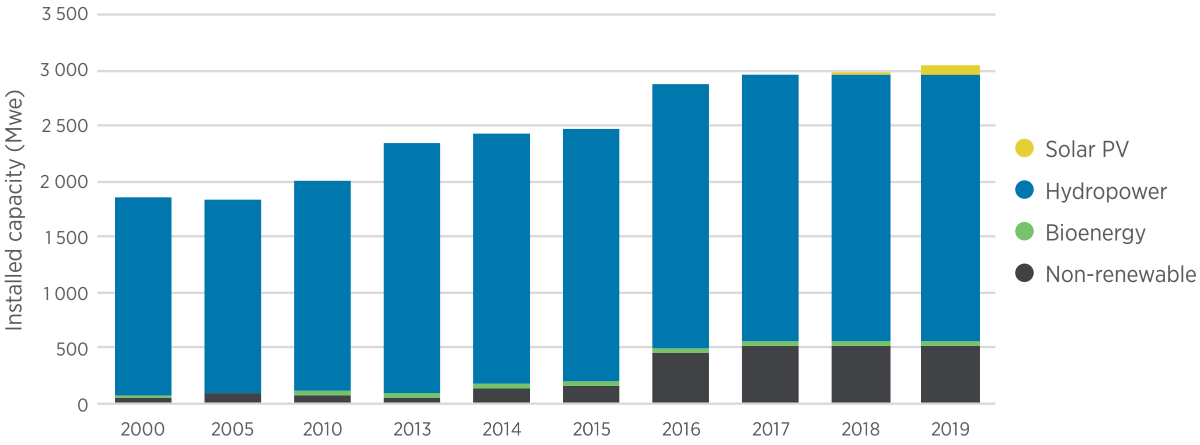
Zambia

Zambia has vast hydropower potential estimated at over 6 000 MWe from the main dams. Nevertheless, only about 2 400 MWe is currently installed (IRENA 2019)(ERB, 2017). The other source of electricity in Zambia is bioenergy, whose status has remained the same since 2010 with an installed capacity of about 43 MWe. Installed capacity from solar has remained very low, while non-renewable sources increased from 80 MWe to 520 MWe between 2010 and 2019 (Figure 40). In addition, Zambia has an off-grid installed capacity of 13 MWe consisting of solar PV (7 MWe), fossil-fuel generation (4 MWe) and hydropower (2 MWe).

In Zambia, domestic fuels production is mainly charcoal and coal (Figure 41). In this context, it is worth underlining that the increase in coal production coincides with the installation of a 30 MWe coal power plant in 2015, whose capacity was increased to 330 MWe in 2016.

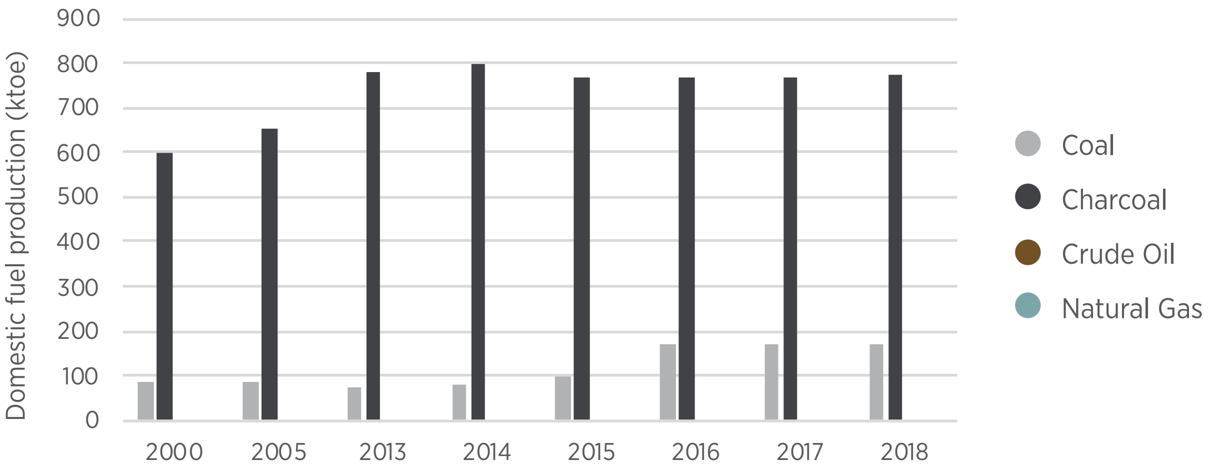
National access to electricity in Zambia in 2017 stood at about 40%. In the same year, urban connectivity was 75%, while rural connectivity between 2000 and 2017 increased from 2% to 13% (Figure 42).

Figure 40: Grid-connected electricity installed capacity trends in Zambia by source



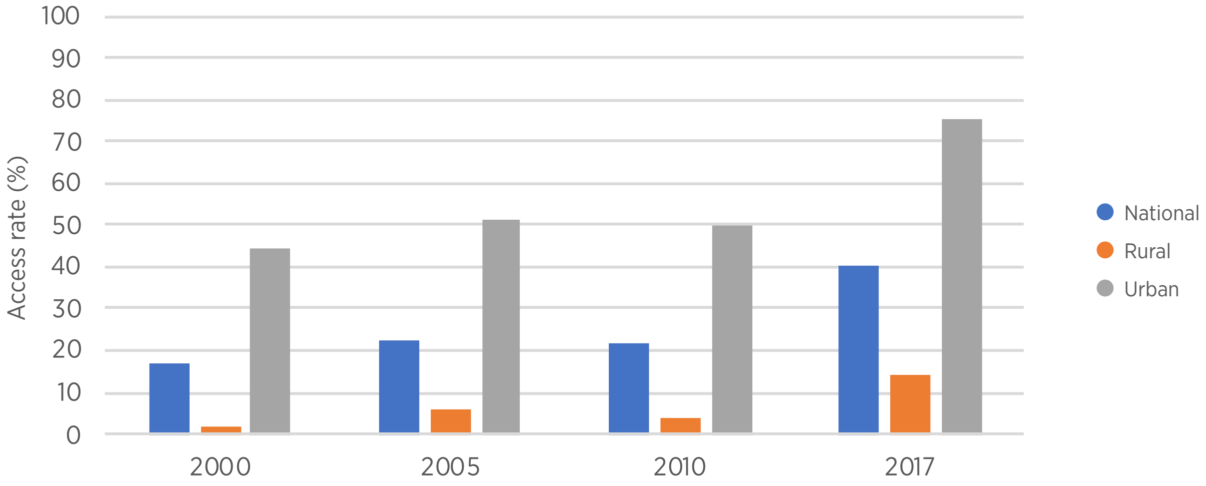
Based on: IRENA (2020a)

Figure 41: Domestic fuels production trends in Zambia by source



Based on: AFREC (2018)

Figure 42: National, urban and rural electricity access trends in Zambia



Based on: UNStats (2019)

With regard to geothermal energy, geothermal surface manifestations have been identified in many geologic environments in the country, ranging from non-volcanic Permian Karoo extensional basins in the south and a late Proterozoic Katangan granitic belt in the north of the country (Legg, 1974). Hot springs discharge along faults and fractures associated with the development of the EARS at Kapisya, Chinyunyu and Kafue trough. The majority of the hot springs occur within the Luangwa rift, which is a southwestern extension of the EARS. The association of the manifestations with geologic structures, and absence of recent volcanism in the areas, can be inferred to imply that all the geothermal resources in the country are of low- to medium-temperature, fracture/fault-controlled systems**.**

Until 2015, all geothermal sites were being developed by the Zambian Ministry of Energy. The government undertook reconnaissance surveys of most of the identified sites, after which Kapisya was identified for development by ZESCO, the state-owned power generation and distribution company. Kalahari Energy Limited was licensed in 2015 to explore and develop one of the prospects at Kafue Gorge. As of May 2020, the company had drilled 18 exploration wells (temperature gradient wells and slim holes) in Bwengwa River prospect. Five of these encountered a shallow geothermal reservoir at about 100°C. Funds have been secured from the Renewable Energy Performance Platform (REPP) to drill an additional three slim holes targeting a deeper reservoir estimated to have temperatures of about 150°C. The results of this drilling will be used in the development of a feasibility study for the geothermal project (REPP, 2020). It is estimated that this medium-temperature resource could be suitable for power generation of about 15 MWe using binary technology within the identified resource area (Vivian-Neal *et al*., 2018).

Kapisya geothermal field is the best-known geothermal area in Zambia. Hot springs occur over a wide area with a maximum temperature of 85°C recorded in some of the hot springs. Fifteen shallow wells drilled to 200m depths encountered hot fluids of over 95°C, which was considered suitable for binary power generation. Line shaft pumps were installed in the wells to provide hot water to power a geothermal plant with 2 x 100 kW turbo-generators, which was constructed in 1986 but never commissioned. The Kapisya geothermal field is under development by ZESCO.

Geothermal resources in Zambia are currently used only on a small scale for direct use in various parts of the country. These include recreation and balneotherapy as well as salt recovery. The main recreational use is at Chinyunyu hot springs area near Lusaka, where there is a hot bath as well as medical use of the hot water. The hot, mineral-rich water (65°C) is utilised for “treatment” of ailments due to its “curative” properties. Private development of a health spa was considered, but the project was not completed. Furthermore, salt recovery through filtration and evaporation from hot springs near Lake Mweru in northern Zambia has been reported (Legg, 1974).

4.

4. POLICIES, REGULATIONS AND INSTITUTIONAL FRAMEWORKS

Supportive policies and conducive regulatory environments are critical for the development and implementation of geothermal projects. This chapter will provide an overview of the policies, regulations and institutional frameworks in Comoros, Djibouti, Ethiopia, Kenya, Tanzania, Uganda and Zambia with the objective of assessing each country's status as well as identifying possible gaps and good practices.

4.1 Status by country

Comoros

Geothermal development in Comoros has been slowed down partly by the absence of an energy policy, strategy and institutional and legislative framework. Prefeasibility studies indicate that geothermal development in Comoros would lead to the generation of cheaper electricity, because most of the electricity generated in the country currently is expensively priced and comes from fossil fuel plants (Anlil-Wafa *et al*., 2018).

The government of Comoros initiated the development of an energy sector regulatory framework with a focus on renewable energy in 2019, by advertising for an expression of interest with the support of UNDP. When developed, the regulatory framework will support the country's efforts to develop local resources such as geothermal. The new regulatory regime will also set the stage for the unbundling of Water and electricity management in the Comoros (MAMWE) and Electricity of Anjouan (EDA).

MAMWE is the national utility company for Grand Comoro and Moheli islands, and EDA is the utility company in Anjouan Island. The companies are responsible for supplying and marketing electricity as well as regulating the electricity sector in their areas of jurisdiction.

Djibouti

In 2014, the Djibouti government launched the "Djibouti Vision 2035", whose goals, among others, include the promotion of 100% electricity generation from renewable energy sources to advance industrialisation and competitive economic development.

In addition, Djibouti set a target of reducing its carbon emissions by up to 40% by 2030. Among the measures planned to help reduce GHG are increased power generation from solar, wind (onshore and offshore), geothermal and hydropower imports from the Ethiopian grid (World Bank, 2017).

In Djibouti, the main institution dealing with policy and regulation of the energy sector is the Ministry of Energy, which oversees the management of natural resources. Until 2015, Electricity of Djibouti (EDD) was responsible for the development of the electricity sector, including geothermal energy resources.

In January 2014, the government set up a specialised geothermal company: the Djiboutian Office for the Development of Geothermal Energy (Office Djiboutien de Développement de l'Energie Géothermique - ODDEG) under Decree 32/AN/13/7ème. ODDEG is supervised by the Presidency of the Republic of Djibouti. This company is in charge of 1) identification of the geothermal resources of the country; 2) conducting reconnaissance and surface exploration studies; 3) undertaking prefeasibility and feasibility studies aimed at the commercial development of the resources and the diversification of their utilisation; and 4) developing partnership with IPPs and other stakeholders to ensure cost-effective development of geothermal energy and any associated products. Other institutions active in the electricity space in Djibouti are Centre des Etudes et la Recherche de Djibouti (CERD - Djibouti Study and Research Center) and National Energy Commission (CNE).

CERD is a public scientific institution with expertise in all specialisations and, prior to the establishment of ODDEG, it was responsible for research on geothermal resources in Djibouti. In October 2009 and by Presidential Decree 11 2009-0218/MERN, CNE was established with the mandate to oversee the development and implementation of the Djibouti National Energy Master Plan.

The government of Djibouti hired a specialised law firm from Iceland to assist in the preparation of a framework for the exploration and development of geothermal resources. The main objective for the contractor was to assist ODDEG and the government of Djibouti to develop a plan for the development of geothermal resources and prepare geothermal legal and regulatory frameworks. The scope of work for the consultant was to review the existing policies and regulations as a basis for the preparation of policies, legal and regulatory framework, and a draft geothermal bill (Mouna and Kayad, 2019). The regulatory framework under development aims to, among other things, open up the electricity generation sector to IPPs.

Ethiopia

In Ethiopia, the Ministry of Water, Irrigation and Electricity is responsible for planning, co-ordinating and providing policy guidance for overall energy development; promoting research and renewable energy technologies; and supervising the following institutions which are directly involved in the energy sector: Ethiopian Electric Power (EEP), Ethiopian Electric Utility (EEU) and Ethiopian Energy Authority (EEA). The Ministry is also in charge of exploration of geothermal and hydrocarbon resources through the GSE. However, the full development of geothermal resources requires the participation of the Ministry of Finance and Economic Cooperation for public financing, the Ministry of Trade for providing tax incentives, and the Ministry of Environment, Forest and Climate Change for environmental policies and regulations (Federal Democratic Republic of Ethiopia, 2016).

EEP is mandated to generate and transmit electricity in Ethiopia and to neighbouring countries. It is also responsible for direct sales to industrial customers and exports to Djibouti, Sudan and Kenya. EEP operates and maintains more than 12 hydropower plants, three wind power plants, a geothermal plant and diesel plants, with a total installed capacity of 4 450 MWe.

EEP is the sole marketer of bulk electricity to the EEU for distribution to customers. The energy sector in Ethiopia is regulated by the EEA, which issues licenses to the other energy sector players in Ethiopia, including IPPs.

The GSE is responsible for mapping of geological features and carrying out investigations related to Ethiopia's natural resources, including geothermal. GSE was instrumental in the early exploration of the geothermal prospects in Ethiopia including in Aluto-Langano, Tendaho, Corbetti, Tulu Moye and all the other major sites in the country. It undertakes all the early stage exploration studies including drill site selection and management of exploration drilling programmes. The prospects are then licensed either to EEP or to private investors to undertake subsequent stages, including power plant development.

The geothermal sector in Ethiopia was previously regulated by Energy Proclamation No. 810/2013 and Mining Operation Proclamation No. 678/2010. However, a new Geothermal Proclamation No. 981/2016 was enacted to exclusively govern the geothermal sector (Federal Democratic Republic of Ethiopia, 2016). The proclamation is the most transformative law governing geothermal resources development among the countries of the East African Rift because it allows for licensing of geothermal resources for power generation and for direct use. It specifically provides for licensing of various categories of geothermal resources, namely Grade I suitable for power generation and combined heat and power (CHP) and Grade II geothermal resources for direct use applications only.

To operate a geothermal power plant, an investor is required to obtain a geothermal operation license from the EEA. A geothermal operation license is issued either directly on-demand or based on competition (for known geothermal resource areas).

The permits issued for Grade I geothermal resources include a reconnaissance license, exploration license and geothermal well-field development as well as geothermal use license depending on the stage of the geothermal projects. Holders of reconnaissance licenses may apply for a geothermal exploration license if they meet the requirements specified in the proclamation.

An exploration license is exclusive and is issued to an investor who has demonstrated financial and technical capability and whose work programme and environmental impact assessment report has obtained the necessary approval from the EEA. The license is issued for a period not exceeding five years and is renewable for a further period of two years on application.

A geothermal well-field development and use license is issued for a period not exceeding eight years for development and 25 years for power generation. The procedure for issuance of an exploration license for Grade II resources that are suitable for direct use only is not provided for in the Geothermal Proclamation but awaits enactment of the regulations for its operationalisation.

The Geothermal Proclamation further provides that licensing of Grade II prospects can be issued by National Regional States considering maximum resource temperatures and volumes to be extracted.

The Ethiopian government through the Geothermal Proclamation provides for incentives that include duty and tax waivers (including valued-added tax [VAT]) on any consumables, equipment, machinery and vehicles required for geothermal project development following an approved work programme.

As part of Ethiopia's Climate Resilient Green Economy Strategy, the Ethiopia government opened the geothermal sector to private investment, and the first geothermal concessions were awarded to a private developer in 2009.

As a result, two PPAs were signed in 2020 for supplying 150 MWe each to the Ethiopian grid from Corbetti and Tulu Moye geothermal prospects (RG, 2020, 2017) (Box 3).

For a streamlined process in the development of geothermal resources, the government is working on a project to rationalise GSE and EEP to form a state corporation responsible for geothermal development fashioned on the model of GDC of Kenya. The company would develop geothermal fields, sell steam to power generators and reinvest the funds into new, early stage geothermal developments. Discussion is underway with stakeholders and financiers on the expected structure of the state corporation.

Ethiopia has opened its geothermal sector to private developers, with concessions for power supply awarded since 2009.

Box 3: PPA and implementation agreement for Corbetti and Tulu Moye geothermal projects in Ethiopia

The PPA and implementation agreement (IA) for the Corbetti and Tulu Moye geothermal projects was signed in March 2020. The objective of the PPA and IA is to create a clear and mutual understanding of the relationship among the developer, the off-taker and the government of Ethiopia for the lifetime of the project. The PPA and IA are comprehensive documents developed over several years with each side represented by experienced lawyers in the IPP sector in Africa.

Photograph 6: Corbetti geothermal project PPA signing ceremony

Photo credit: InfraCo Africa

These documents, among other things, include details of tariffs, phasing, dispatch, foreign exchange, licensing, change in law, *force majeure*, dispute resolution and termination. They take into account the geothermal regulatory environment in Ethiopia and include a construction period and a 25-year operating period, after which the power plants can revert to the Ethiopian government in a build-own-operate-transfer (BOOT) development model. Reducing commercial uncertainty and ensuring the financial sustainability of both the projects and the off-taker is essential, as these contribute to fulfilling the stringent requirements of project finance lenders to achieve bankability, thus allowing for the successful financing of the total USD 1.6 billion investment for the 2 x 150 MWe projects.

All of the projects' stakeholders were involved at various stages of developing the PPA and IA, including project sponsors and the government of Ethiopia through the EEP, EEA, the Ministry of Water, Irrigation and Energy and the Ministry of Finance and Economic Cooperation, the regional authorities, and the Ethiopian Parliament.

Kenya

The Least Cost Power Development Plan 2017-2037 for Kenya envisages having a total installed electricity capacity of 9 932 MWe by 2037 from all energy sources. The contribution of geothermal in the power mix would be 2 647 MWe, equivalent to about 27% of the total installed electricity capacity (Government of Kenya, 2018).

Over the last four decades, the government of Kenya has played an active role in developing geothermal energy, as well as supporting programmes to build expertise in the development of geothermal energy. In particular, the country is considered a successful case study of the government playing the role of a geothermal developer through the activities of various public sector entities (ESMAP, 2016b). However, the country is pursuing a strategy to incentivise the involvement of the private sector, including in greenfield development since 1997.

The Electric Power Act of 1997 redefined the scope of Kenya Power and Lighting Company (KPLC). This limited its mandate to the transmission and distribution of electricity. At the same time, the Kenya Electricity Generating Company (KenGen), which was rebranded from Kenya Power Company in 1997, was mandated to undertake electricity generation functions. The act also paved the way for IPPs to enter the electricity generation market. The first private geothermal IPP in Kenya was licensed in 2000 to develop Olkaria III geothermal field.

Sessional Paper No. 4 of 2004 and the Energy Act No. 12 of 2006 further proposed additional restructuring of the electricity sector by unbundling transmission and distribution functions. Kenya Electricity Transmission Company Ltd (KETRACO) was established in 2008 to take up the transmission function of new power lines, while KPLC retained the distribution function as well as the management of existing transmission lines.

The restructuring also established the Geothermal Development Company (GDC), which was incorporated to undertake the upstream stages of geothermal exploration and development (Box 4).

GDC's main role is, therefore, to conduct surface exploration of geothermal prospects as well as carry out exploratory, appraisal and production drilling.

Box 4: Unbundling the electricity subsector to catalyse geothermal development

Kenya, in an effort to enhance efficiency in the development and delivery of electricity services, commenced the unbundling of the subsector in 1997 with the separation of the management of KenGen from that of KPLC. The government of Kenya is the major shareholder of KenGen, with a 70% controlling stake. KenGen was mandated to generate power from all sources, including geothermal, while KPLC was mandated to transmit and distribute power. Since then, geothermal power developed by the public sector (through KenGen) has increased from 45 MWe in 1997 to 706 MWe in 2019.

In 2008, the Kenya government established the GDC to carry out early stage development of geothermal resources, hence reducing the high upfront risks and taking on the high front-loaded costs of geothermal development. The object was to facilitate private sector participation in geothermal development, thereby accelerating the deployment of geothermal energy. This led to the opening up of the greenfield of Menengai through the drilling of geothermal wells as well as the development of a steam gathering system (see Box 2). GDC is also undertaking the development of the Baringo-Silale geothermal block, where exploration wells have been successfully drilled.

Geothermal resource development in Kenya is subject to both national and international legal and regulatory guidelines to ensure sustainability. These include the Constitution of Kenya 2010, the Energy Act 2019, policies and regulations, and several acts of parliament. Other laws and regulations include World Bank Safeguard Policies, relevant international conventions and treaties, the Environmental Management and Coordination Act (1999) and associated regulations enacted in 2003 that govern the environmental sustainability of geothermal projects.

These laws and regulations have been enacted to streamline and attract renewable energy investment while protecting the environment. There are other laws and regulations not designed specifically for geothermal energy but impact geothermal development, including the PPP Act of 2013 and subsequent regulations of 2014.

The Energy Act 2019 established the Renewable Energy Resource Advisory Committee (RERAC) under the Ministry of Energy with the mandate of advising the cabinet secretary on the licensing and management of renewable energy projects. The act also established the Energy and Petroleum Regulatory Authority (EPRA) as the regulator of the energy sector.

The Energy Act 2019 consolidated the all the energy related laws in Kenya and replaced the Energy Act of 2006 and the Geothermal Resources Act 1982. It provides for the roles of the national and county government on energy matters, including promotion, recovery and commercial utilisation of geothermal resources in the country. The act further establishes and sets functions of the energy sector entities. For the first time, the act recognises the potential role of direct use of geothermal resources, and states that the necessary regulations to govern the exploration and utilisation of geothermal energy through direct use will be made on advice from RERAC.

Licensing of geothermal concessions was previously undertaken through non-competitive Privately Initiated Investment Proposal (PIIP) or by procurement through a competitive bidding process. This would be done in accordance with the PPP Act of 2013 and Regulations thereof of 2014, as well as the Geothermal Resources Act No. 12 of 1982 (Government of Kenya, 1982) and the subsequent Regulations (Government of Kenya, 1990). With the enactment of the Energy Act of 2019, new licenses will be issued according to the new act and constitution of Kenya 2010. The Geothermal Resources License is issued for a 30-year period with the option of a 5-year extension. The license has tight timelines to achieve various development milestones, and it may be revoked if these milestones are not achieved. Among the fees payable by the licensee are a land rental fee payable annually and a further levy of 1-5% for each kWh of energy sold as royalty fee to the government. This fee would then be shared among the local community, county government and national government in predetermined ratios.

Kenya’s feed-in tariff policy, which took effect in 2008 and was revised in 2012, includes a fixed tariff for various renewable energy sources, including geothermal, hydropower, solar and wind (Ministry of Energy, 2012). The Energy Act of 2019 retained the feed-in tariff regime to encourage investment in renewable power projects, including the development of renewable-based distributed electricity generation systems. This would in turn contribute to an increase in the electrification rate without the need to extend the national grid. It is also hoped that the feed-in tariff for geothermal, which is set at USD 0.088/kWh, will help spur new geothermal projects.

The government of Kenya, through Public-Private Partnership (PPP) Act No. 15 of 2013 and associated Regulations of 2014, developed a framework to guide the engagement of the private sector in the financing, development and management of public infrastructure projects. The act also established the institutions responsible for regulating, monitoring and supervising the implementation of PPP project agreements. The government considers geothermal projects to be some of the infrastructure projects that are eligible and well suited for PPP arrangements.

The Kenyan government has since 2003 been supporting the geothermal sector with direct financing through the medium-term expenditure framework process in the form of subsidies and grants. For example, the Kenyan government spent KES 20 billion (Kenyan shillings; USD 188.5 million) on geothermal development in 2015/2016 through both GDC and KenGen (Kiptanui and Panga, 2018). The cumulative government financial support for the two institutions was more than USD 5 billion between 2003 and 2016 (Kiptanui and Panga, 2018). Most of the financial support to GDC was for resource evaluation, exploration, appraisal and production drilling while concessionary loans lent to KenGen were for power plant developments.

In terms of incentives, the government of Kenya has been providing tax exemptions on geothermal equipment and machinery. The tax incentives include waiver of customs duty and zero rating of VAT in the "procurement of power plant equipment and related accessories for geothermal power generation and transmission during project implementation." However, in response to the COVID-19 pandemic, the government passed the Tax Law Amendments Bill 2020 which proposed to introduce a 14% VAT on equipment for geothermal prospecting and exploration, as well as equipment for the construction of power plants to supply electricity to the grid (EY, 2020). Other tax exemptions offered to geothermal investors include the following: i) no taxations on interest accruing from externally sourced debt finance for geothermal projects (National Treasury's Legal Notice 91 of 2015); ii) no withholding tax on the renumeration paid to external consultants for services rendered relating to PPAs (Legal Notice 165 of 2015); and iii) no stamp duty on registering collateral for externally sourced debt for utilisation in geothermal projects (Legal Notice 106 of 2015). Finally, the government offers a tax holiday for geothermal power plants as well as dividend incomes for investments made from domestic sources.

The government provides private investors with letters of support to cover political risks and ease the financing of their projects from the international market as stated in the Energy Act 2019 (Government of Kenya, 2019). However, the legal weight of the letters of support has been questioned after it was watered down following an arbitration case that the government faced following the discontinuation of the Kinangop IPP wind project due to social unrest. The government of Kenya, supported by the African Development Bank, also set up a partial risk guarantee for geothermal projects to protect geothermal investments from political risk (see Chapter 5 for further details).

Tanzania

The Ministry of Energy and Minerals (MEM) is responsible for the development of the electricity supply systems in Tanzania. MEM provides strategic guidance to the sector through the setting of policies, strategies, laws and roadmaps, and supporting energy infrastructure development. The main player in the sector is Tanzania Electric Supply Company (TANESCO), which is a public institution with the mandate to generate, transmit and distribute electricity as well as supply bulk power to the Zanzibar Electric Company. TANESCO currently owns about 78% of the installed electricity capacity in Tanzania.

The sector is regulated by the Electricity and Water Utilities Regulatory Authority (EWURA). The sectors that are regulated by EWURA include the electricity, natural gas, petroleum and water sectors. In this regard, EWURA is responsible for licensing power generation, developing and enforcing quality codes and standards, reviewing and setting retail tariffs, and approving PPAs with emergency power producers (EPPs), IPPs, and small power producers (SPPs). Under the Electricity Act 2008, EWURA also reviews and approves all energy projects in Tanzania.

Under the Electricity Act of 2008 and National Energy Policy of 2015, the electricity supply industry was restructured to provide for the participation of the private sector in the electricity sub-sector through IPPs, as well as EPPs and SPPs. TANESCO acts as the sole off-taker of electricity generated by IPPs, EPPs and SPPs and, together with EWURA and MEM, negotiates PPAs which are then approved by EWURA.

The Rural Energy Agency is an autonomous government agency under MEM which is responsible for the promotion and development of rural electrification projects by co-financing rural electrification programmes implemented by relevant actors.

Tanzania Geothermal Development Company (TGDC) was formed in 2013 as a subsidiary of TANESCO. Its focus is on geothermal resource development, with a mission to de-risk geothermal projects for further development by public or private players. Its activities include mobilisation of low-cost finance for project implementation and developing required local capabilities to implement projects. The Energy Policy of 2015 sets out the government's objectives for the geothermal sector, including to encourage private sector investment in geothermal development through concession arrangement or PPP.

The first IPP geothermal license was issued in Tanzania in 1997 and an additional 30 licenses were issued between 2011 and 2013 under the Mining Act, but all were cancelled by 2014 due to what the government considered to be slow progress against the license conditions (JICA, 2014). By the end of 2019, no licenses had been issued to private developers even though the Energy Policy of 2015 envisaged their increased involvement in geothermal development to meet the electricity generation target of 200 MWe from geothermal sources (Norton Rose Fulbright, 2017). The Tanzanian government is considering developing a geothermal act to help spur development in the sector through private investment.

Uganda

The institutional setup of Uganda's electricity sector comprises the Electricity Regulatory Authority (ERA), Ministry of Energy and Mineral Development, Uganda Electricity Distribution Company Limited, Uganda Electricity Generation Company Limited and Uganda Electricity Transmission Company Limited (UETCL).

ERA as the sector regulator issues power generation, transmission, distribution, sale and import licenses; sets terms for the license; and enforces compliance to license terms according to the Electricity Act 1999. ERA also establishes the power tariff structure and approves the electricity charges. Electricity transmission is solely the responsibility of UETCL, which executes PPAs and operates the power transmission infrastructure. UETCL, together with its operation and management partner, Eskom Uganda Limited, is the main generator of electricity in Uganda. All power generators feed into the national grid, and the electricity generated is distributed to electricity consumers by distribution companies, of which Umeme Ltd has the largest customer base out of the current eight distributors.

The Ministry of Energy and Mineral Development has further undergone restructuring and a separate department headed by a commissioner, the Geothermal Resources Department, has been established to handle activities relating to geothermal exploration and development. To address the challenges of financing geothermal and other renewable power projects, the government established the Uganda Energy Credit Capitalisation Company (UECCC) as a wholly government-owned institution to provide necessary financial support to the projects.

The licensing for geothermal resource evaluation and development is undertaken under the Mining Act of 2003. The exploration license grants the license holder authority to prospect for geothermal resources for three years. This license can be renewed twice for a further duration of two years for each renewal. If exploration is successful, the developer is required to apply for a generation licence with the ERA under the Electricity Act of 1999. As of 2020, three companies held geothermal licenses in Uganda: Gids Consult Ltd has a geothermal license in Buranga, Moto Geothermal Projekt Limited has a geothermal license in Ihimbo, and Bantu Energy Uganda Limited has a license in Panyigoro prospect. The other more than 20 prospects are under exploration by the government of Uganda through the Ministry of Energy and Mineral Development.

Uganda's Renewable Energy Policy of 2007 provides a framework to increase the contribution of renewables in the country's energy generation mix to 61% by 2025.

The Renewable Energy policy further provides for a feed-in tariff of USD 0.077/KWh for geothermal to offer a predictable business environment in the sector. Furthermore, the Uganda government in 2016 started drafting a new geothermal policy to streamline the development of geothermal energy projects (Government of Uganda, 2016). The policy seeks to harmonise the existing policy frameworks on geothermal energy development to fast-track projects for power production and other uses.

Zambia

Grid hydro-electric power development has been the main focus of Zambia's energy planning as per the Energy Policy of 1994 and the subsequent Energy Policy of 2008. Though the Poverty Reduction Strategy Paper (PRSP) calls for the development of renewable energy resources in Zambia, it provides neither specific targets to be achieved nor an investment strategy to meet the country's energy needs.

The Ministry of Energy is responsible for energy policy development, while the Energy Regulation Board (ERB) is responsible for licensing of renewable energy projects governed by the Energy Regulation Act of 2019. However, Zambia does not have a dedicated geothermal regulatory framework.

ZESCO is the state corporation mandated to generate, transmit and distribute electricity in Zambia and reports to the Ministry of Energy.

In addition to a major lack of adequate human resource capacity in all segments of the sector, Zambia lacks policies and suitable legal and regulatory frameworks which would guide and promote geothermal development. The off-taker risk is also considered high in the country. In the absence of a geothermal law, geothermal projects are governed by the Energy Act, which provides for private sector entry but lacks fundamental regulations that would help fast-track geothermal projects. The absence of a geothermal law, when coupled with fundraising challenges, has resulted in slow growth of the geothermal sector.

To support the development of renewable energy technologies, including geothermal, complementary renewable energy-focused regulatory and institutional frameworks are required, in addition to government sponsored financial incentives.

Complementary energy-focused frameworks are needed to synchronise geothermal projects with other renewable energy development.

4.2 Lessons learned and perspectives

For many of the countries in the region, hydropower or fossil fuels are the main sources of electricity. With the cost of generation (LCOE) from renewable technologies dropping and the world embracing renewable energy technologies, the countries of the region have started looking at all options available for a sustainable energy mix. In Kenya, geothermal has been positioned as the main source of electricity for the country in the short- and medium-term (2030), while solar and wind generation are also expected to grow. Other countries like Djibouti have developed long-term energy plans with clear perspectives for growth and investment in geothermal energy. Therefore, long-term and stable energy mix plans for countries may be considered as a critical first step allowing for mainstreaming of geothermal as an important energy source.

Long-term planning can be the first step to bring geothermal into the mainstream energy mix.

The above analysis (see Chapter 4, Section 1) shows that the policies and regulatory frameworks governing the exploration and development of the geothermal energy resources in the region vary significantly among the countries or are altogether absent in some countries. In particular, with the exception of Ethiopia, there is no dedicated framework or licensing procedures for standalone direct use projects. Chapter 6 of this report provides some recommendations for countries to fill this gap and seize the opportunities for geothermal energy beyond power generation.

During the consultation process carried out in the preparation of this report, geothermal developers and IPPs who are active in the region indicated that the laws and regulations put in place in Kenya and Ethiopia are largely adequate to support geothermal electricity development.

However, some geothermal developers who are not actively engaged in developing geothermal resources in the region indicated that clear and transparent procedures as well as consistent energy policies are a necessity for them to consider a possible involvement in the sector.

In particular, some companies suggested that the permitting procedures for geothermal concessions should put greater weight on the ability of the licensee to perform, *e.g.* by demonstrable technical expertise and financial strength as opposed to the current case where it is based on defined timelines, as this could produce more optimal results. For countries that have not enacted geothermal laws, it is important to establish clear and transparent licensing procedures to help reduce project risks and attract private investments.

Furthermore, the above analysis indicates how PPAs are one of the essential requirements for reaching financial closure for geothermal projects. So far, however, only IPPs in Ethiopia and Kenya have been successful in negotiating PPAs with the respective governments. Shorter durations for negotiating PPAs between the generator and the off-taker are desirable for private sector investment, as delays have negative cost implications on the projects. Additionally, the PPAs should be project-specific as each project requires a different set of incentives, which take into consideration the resource characteristics and project location. Generally, the IPPs indicated that a good PPA should address the following: political risks, legal risks, construction risks, operations risks, financing risks, and market and revenue risks (for a more detailed overview of risks related to geothermal projects and mitigation instruments, see Chapter 5, Section 1).

In addition, some IPPs participating in the consultation indicated that national geothermal-specific programmes may be beneficial to complement those already available at a regional level that have been developed in collaboration with development partners (see Chapter 5).

In this regard, some of the policy instruments that have led to successful geothermal development in Kenya, such as feed-in tariffs, tax exemptions, budgetary support, *etc.*, may be considered by other countries in the region.

As observed in the countries of the EARS, geothermal development may be accelerated by direct government involvement through specialised agencies such as KenGen and GDC in Kenya or through enabling the private sector to participate in greenfield development, as is being witnessed in Ethiopia. In this regard, policies and regulations that allow for healthy development of a geothermal market for IPPs, PPPs and public entities should be established.

Another element that has emerged so far (see Chapter 3 in particular) is that many of the unexploited geothermal fields are found in remote areas with limited or no access to the national grid. As a strategy of electrifying such areas, governments and the private sector in the region are developing off-grid solutions, most of which are based on solar energy. In this context, it is worth highlighting that Oserian Development Company in Naivasha, Kenya, generates electricity for self-consumption from two wellhead power generation units with a combined installed capacity of 3.6 MWe.

Although this cannot be considered an example of an off-grid project due to the nearby large-scale geothermal development connected to the grid at Olkaria, this example may pave the way for the development of geothermal resources in remote areas without a connection to the national grid.

In this regard, some geothermal developers and IPPs have also expressed willingness to develop similar small-sized geothermal power plants with well-head technology in remote areas if a conducive regulatory environment is in place. In particular, the developer would require incentives in electricity pricing as this technology tends to require a higher tariff than for large-size plants.

The financial viability of small-size power plants for on-grid and off-grid connection could be enhanced by implementing diversified uses of the resource, including direct uses and cascaded utilisation, as demonstrated through feasibility studies in the case of Uganda (see Chapter 3).

The well-head technology may be well suited for areas where geothermal energy could be used to power end-use sectors such as in water pumping, local industrial activities and agri-food operations – areas where extension of the grid would not make economic sense.

5.

5. GEOTHERMAL FINANCING AND DEVELOPMENT MODELS

This chapter presents the main risks associated with geothermal energy projects in the EARS region and discusses how development models, strategies and instruments for financing geothermal projects have evolved over time. The section also presents the advantages and disadvantages of the various options and identifies lessons learned and possible strategies to improve the financial viability of geothermal projects.

5.1 Introduction to geothermal project financing and risks

Equity investors in geothermal projects in the East African Rift countries typically require an internal rate of return (IRR)[7] exceeding 15%, and development finance institution (DFI) lenders will charge interest rates between 6% and 8%. Commercial lenders have yet to participate in the EAR geothermal market, and their current risk aversion may result in unattractive interest rates. Geothermal projects require high upfront investments, and thus the cost of finance is an important consideration to assess their viability and competitiveness.

Due to the potential geothermal resource uncertainty, front-loaded cost structure and long development timeframe, investors generally perceive risks in geothermal projects as high. A list of the main risks associated with electricity projects in general, and more specifically geothermal projects, is provided in Box 5.

Stable financing mechanisms are needed to provide stability and reduce actual and perceived project risks.

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[7] The internal rate of return (IRR) is a value calculated to evaluate the profitability of potential investments. It can be compared to a hurdle rate or discount rate and needs to be at least at a similar level as the weighted average cost of capital (WACC) in order to indicate a potential profitable investment.

Box 5: Risks in geothermal development

There is generally no accepted classification of risks that affect energy projects. The list below includes the most common categories, some of which overlap and combine perils (the risk *per se*), insured events (what triggers the payment) and different types of counterparty (government, corporate and private).

1. **Foreign exchange risk (hedge):** Most of the capital expenditure and the loans used for energy projects will be denominated in hard currency, while the users of electricity will pay in local currency. The PPA will identify how the resulting currency exchange risk is allocated between the producer and the off-taker. Both banks and specialised institutions can protect companies against the foreign exchange risk in case the exchange rate between two currencies fluctuates beyond certain limits. Different products cover this risk.
2. **Natural disasters:** Protection against the risk of financial losses due directly to natural disasters. For geothermal projects, earthquakes are the most obvious risk. Induced micro-seismicity may occur, but the magnitudes are often relatively low in the rifts. The insurance of these risks is sometimes combined with human-made events like war and civil war. In that case, the term that is most commonly used is *force majeure*. The responsibility for losses due to natural catastrophe is one of the typical discussion points in the negotiation of a PPA. Cover is mostly provided by general insurers (property and casualty insurers).
3. **Confiscation, expropriation, nationalisation:** Compensation of financial damage due to loss of property following a government's actions is one of the risks typically included in "political risk insurance". The definition can vary from one insurance policy to another.
4. **Currency inconvertibility and transfer restrictions**: This risk covers two scenarios: impossibility to convert local currency into the international currency of the contract and impossibility to transfer the international currency outside the country of the project.
5. **War, civil war, social unrest, political violence and sabotage**: Material loss due to one of the events listed in the caption. These risks are either covered under a comprehensive political risk insurance or as a stand-alone "political violence, terrorism and sabotage". The triggers for payment of the claim may be very different. Some of these events will also be included in *force majeure* clauses of PPAs and other contractual documents.
6. **Unfair calling of bonds**: The risk that the beneficiary of a surety bond (normally a government entity) calls a surety bond (bid bond, performance bond, *etc.*) without having a valid reason. This risk will be mostly relevant for drilling companies that have been contracted by a government entity.
7. **Non-honouring of sovereign obligation**: Breach of contract by the central government. This can be a financial obligation (non-repayment of a loan, non-respect of a tax exemption), or a performance obligation (*e.g.,* construction of a road or transmission line that connects the power plant). Most insurers will restrict the term "sovereign" to obligations that have been signed by a country's ministry of finance.
8. **Non-honouring of sub-sovereign obligation**: Breach of contract by a government entity that is not the central government or ministry of finance, and where the latter has not given a guarantee. This would be the case if the off-taker does not honour payment, or a stem field developer fails to supply (adequate) steam.
9. **License cancellation**: Cancellation or non-renewal of license(s) issued by the government (*e.g.*, to an IPP) in circumstances beyond the control of the insured, which prevents the insured from fulfilling the terms of the contract. Usually, the condition is that the cancellation is discriminatory.

10. **Liquidity risk**: In the context of renewable energy, this is typically the risk that an IPP will not be paid on time by the off-taker (and therefore will not be able to continue its operations or service its debt). The risk can be covered through an escrow account, a letter of credit or a guarantee instrument.
11. **Resource risk**: In geothermal projects, the short-term risk is related to the possibility that the resource is not found or that a well is not sufficiently productive, while the long-term risk is mostly related to reduced well productivity throughout the lifetime of a project due to reduced flow rate/pressure and temperature drops. Regarding the latter, adequate reservoir management is critical (Ram, 2018).
12. **Construction risk**: Delay or non-performance in the development of the geothermal field or construction of the power plant. This could occur due to a delay in obtaining required authorisations or reaching financial closure, among other reasons.

Additional risks, for which insurance and guarantees usually are not available, include:

13. **Regulatory risk:** Risk that a non-discriminatory change in law or regulations affects the viability of the project.
14. **Environmental and social impact:** In the context of geothermal projects, the main risk is that local communities oppose the project and that their actions impact the development or operation of the power plant.

Given this background, the high-risk perception adds a risk premium to projects, which may limit access to affordable capital (IRENA, 2016b). However, risk mitigation instruments can help mobilise capital in renewable energy investment by addressing these types of risks.

The most important providers of risk mitigation for geothermal development include DFIs, export credit agencies (ECAs), and multilateral development institutions. The DFIs, usually established by charitable organisations or governments, offer support to projects which commercial bank might be unwilling or unable to finance.

The social impact of a project is one of the main guiding principles applied by most development banks in the selection of projects to finance and therefore, major governments use them to channel their development aid. AFD (France) and KfW (Germany) are examples of DFIs active in the geothermal sector.

ECAs support local businesses to carry out exports or invest in international markets by providing financing for operational activities and insurance against business and political risks in other countries. ECAs can be publicly or privately owned and usually provide support to equity investors and technology suppliers.

Multilateral development institutions are international financial entities sponsored by at least two countries to encourage economic development. Their main object is to support the achievement of development goals, rather than generate profits for the shareholders. MIGA (World Bank Group), ATI (Africa Trade Insurance) and AfDB (African Development Bank) have supported geothermal projects in the past.

IRENA's Risk Assessment and Mitigation Platform (RAMP) provides insights on the available risk mitigation solutions and aims to facilitate access to the solutions (Box 6).

Box 6: Project risks and IRENA's Risk Assessment and Mitigation Platform (RAMP)

Geothermal and other renewable energy projects around the world, including those located in EARS countries, face several risks. Investors and lenders will try to mitigate these risks, transfer them to the host country, or cede them to a third party. If this is not possible, they will either abandon the project or ask for a risk premium that can affect the viability of the project itself.

Risk mitigation presents a hurdle for many renewable energy projects. Recognising the challenge, IRENA has set out to map and explain the insurance and guarantee options that exist for renewable energy projects through the Risk Assessment and Mitigation Platform (RAMP).

RAMP provides a categorisation of risks such as resource risks, foreign exchange risks, natural disaster as well as credit and political risks. The platform lists the number of available risk mitigation solutions for each of these categories of risks. Furthermore, RAMP classifies the providers of risk mitigation solutions into relevant categories such as commercial insurers, development banks, export credit agencies, licensed brokers and multilateral insurers, indicating the number of risk mitigation providers per category. The number of providers of risk mitigation solutions per region is also indicated.

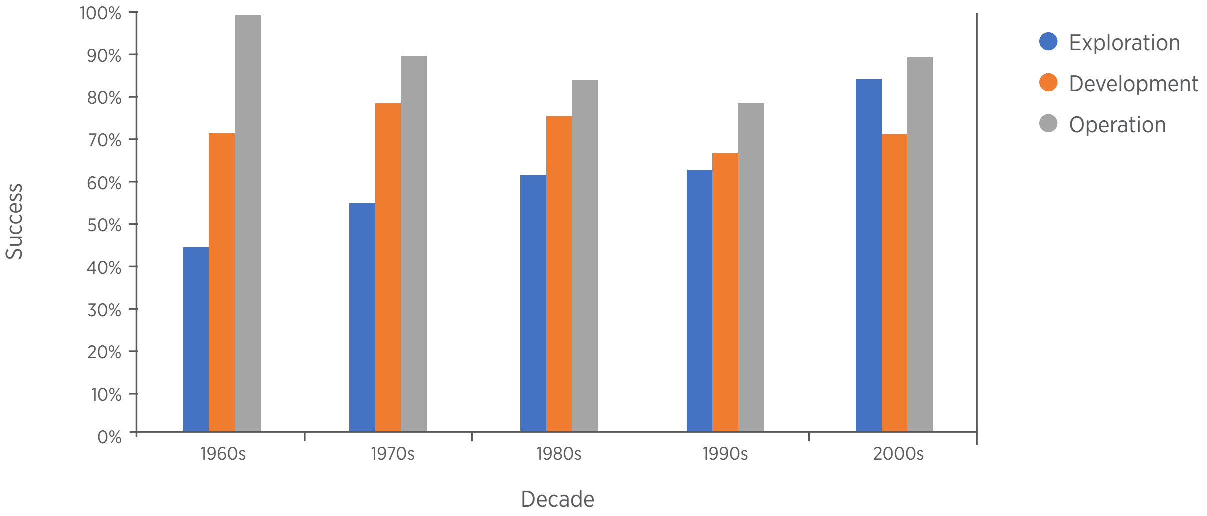
Users can access the platform and identify possible risk mitigation solutions for a given risk in a given country/region. Users can then go through the details of the eligibility criteria, documentation requirements, due diligence, *etc.* of the potential providers and find out what the realistic options are. Furthermore, they can contact providers of risk mitigation and specialised intermediaries directly from the platform.

RAMP can be accessed at http://ramp.irena.org/.

Compared to other renewable energy technologies, a peculiarity of geothermal projects, especially those located in greenfields, is the high resource risk during the exploration phase. This resource risk is derived from the fact that the significant upfront cost for surface studies, exploration drilling and appraisal drilling is required before the existence of a geothermal resource is confirmed, and therefore before project profitability can be determined (ESMAP, 2012, 2016b, 2018). This makes it difficult to raise debt finance until the resource has been proven, leading to a large initial equity requirement. As a result, the expected return on equity is usually high (IFC, 2013). This has therefore led to the realisation that successful geothermal projects require appropriate risk allocation among the private and public sectors and financial institutions.

It is however worth noting that, despite the perceived high-risk profile of geothermal exploration projects, the actual risk has reduced considerably over the years due to a combination of factors such as improved exploration techniques and resource modelling techniques, as shown in Figure 43.

Figure 43: Drilling success rate over time, by project phase



Source: IFC (2013)

It can be observed that the success rate of drilling the first five (exploration) wells has substantially increased from around 45% in the 1960s to around 85% in the 2000s.

High-quality resource modelling and improved resource exploration methods have reduced geothermal drilling risks

A typical ~2 500 m geothermal well may cost on average about USD 7 million, although this varies considerably by geography (Robertson-Tait *et.al*, 2017). Costs related to exploration for geothermal power projects can be as high as 15% of the capital cost requirements of the project. The time required to complete this phase of study is at least three years (ESMAP, 2016b). Several projects in East African Rift countries have stalled due to a failure to raise adequate capital (equity finance and loans) for the exploration drilling stage.

The feasibility of financing of geothermal projects in East African Rift countries is, to some extent, determined by the location and characteristics of the projects, as some sites are considered riskier than others. As an example, projects associated with Quaternary volcanoes in the eastern branch of EARS are considered to have a lower risk as high-temperature resources are expected to be present. In contrast, geothermal projects in the western branch of EARS are considered to have a higher risk because the resources are expected to be smaller and will probably have lower resource temperatures. However, as presented in more detail in Chapter 7, the new exploration strategy proposed for the western branch of EARS could increase the probability of resource discovery, and hence lower the exploration risk (Omenda *et al.*, 2016a).

The geothermal stakeholders interviewed during the preparation of this geothermal assessment report indicated that commercial banks were reluctant to participate in the geothermal exploration phase. This phase of the project in the region has traditionally been financed through public sources, but lately, private developers have developed an appetite for greenfield developments. Besides the high upfront risk of development, stakeholders indicated that some of the factors leading to a lack of financing for geothermal projects include limited geothermal financing experience by local financial institutions; inadequate business models for power and direct use development; limited government access to financial/risk mitigation instruments; and a lack of heat tariffs and heat purchase agreements to assure cash flow for direct use.

5.2 Financing options

The financing options available for geothermal projects include public sources, grants and concessional finance, complemented by technical assistance from support programmes. The following section provides an overview of how the above options have been applied in the context of geothermal development in the region.

Public finance

Successful geothermal projects so far in Kenya are those that have benefitted from public resources to undertake early stage development. Public finance was used in all the successful projects starting with the development of Olkaria's 45 MWe where the state agency covered the co-financing costs with a guarantee from the government. The more rapid growth of geothermal projects in Kenya was due to direct financing from the exchequer, in addition to channelling of concessional loans for appraisal and production drilling at Olkaria I, II, IV and V projects using funds from the China Exim Bank. In Kenya, public finance was used to establish the Geothermal Development Company (GDC) with a mandate to undertake early stage geothermal development to allow for private investment entry. With this approach, financing from government and contribution from concessional funds resulted in the development of the Menengai geothermal field from a greenfield to the current steam status to allow for private investment. GDC is also developing other greenfield projects in the north rift before inviting private investors to bid for production drilling and power plant development.

In Tanzania, the government established Tanzania Geothermal Development Company (TGDC) to undertake reconnaissance and early stage development of all geothermal prospects in the country with funding largely contributed by the exchequer. The company has undertaken detailed surface studies in Ngozi, Songwe and Kiejo-Mbaka and committed the prospects to drilling using two drill rigs which have been financed by the government (Kajugus, Kabaka and Mnjokava, 2018). The tender for the supply of the two rigs was advertised in February 2020. In this context, private investors are expected to take up the projects from the appraisal drilling phase.

The Djibouti Office for Development of Geothermal Energy (ODDEG), an agency of the Djibouti government, is involved in surface studies and confirmatory drilling in Gale-Le-Koma, North Ghoubhet and Arta geothermal areas using concessionary loans from the Arab Fund for Economic and Social Development and Kuwait Fund for Arab Economic Development, which are guaranteed by the Djibouti government.

In Ethiopia, public finance together with funds from the World Bank were used to co-finance the Aluto-Langano's 8.5 MWe pilot geothermal project commissioned in 1998. The government is co-financing the current expansion, which will see production drilling expanded (Kebede and Woldemariam, 2018). The power project is managed by the Ethiopian Electric Power Company (EEP), which is state-owned. The government, through GSE, undertook studies and exploration drilling of the Tendaho geothermal field, Doubti and Alalobeda. Other government-financed geothermal projects in the East Africa Rift countries include exploration and appraisal drilling in Djibouti, exploration of the Alid project in Eritrea; exploration and TGH drilling at Kibiro in Uganda, and the 100% government-financed exploration drilling at the Karisimbi geothermal project site in Rwanda.

Private finance

Early geothermal developments in East Africa were funded by private investors who developed the resources for their own use, *e.g.*, a geothermal-heated pyrethrum dryer developed in 1939 in Eburru, Kenya and the 0.2 MWe power plant in Kiabukwa in DRC in 1952, which was used for supplying power to a mine. It was not until 2000 that OrPower 4, Inc. invested in a new power project in Kenya using balance sheet financing co-financed by International Finance Corporation (IFC). Since then, the governments of Ethiopia, Kenya and Uganda have licensed several greenfield concessions to private developers for power projects.

A case in point is the 150 MWe Corbetti geothermal project in Ethiopia being developed by a consortium involving Reykjavik Geothermal Ltd and other private investors. Also, in Ethiopia, the 150 MWe Tulu Moye geothermal project is being developed by Tulu Moye Geothermal Operations (TMGO), a consortium between Meridiam, Inc. (a French project developer new to the geothermal sector) and Reykjavik Geothermal Ltd. As of March 2020, the consortium had started exploration drilling after the completion of detailed surface studies programme. TMGO has benefitted from a Geothermal Risk Mitigation Facility (GRMF) surface study grant, and both the Corbetti and Tulu Moye projects are awaiting final approval for drilling grants from GRMF.

In Kenya, between 2008 and 2019, 14 greenfield prospects were licensed to private developers with the requirement to undertake surface studies and exploratory drilling within three years of license issuance. To overcome financial constraints and risks that come with early stage geothermal developments, the developers have invited bids from local and international equity shareholders, including investment funds. Another innovation, and a first for geothermal development in Kenya, was KenGen's Public Infrastructure Bond Offer (PIBO), which raised more than USD 150 million through the Nairobi Securities Exchange (NSE) for electricity generation capacity expansion. According to local media, the PIBO contributed to the increase in installed electric capacity by KenGen from all sources including geothermal power from 1021 MWe in 2009 to 1631 MWe in 2019, an increase of 60% over the bond's maturity period (Capital Business, 2019). Another new innovative financing method being considered is asset-backed securities, where steam could function as the security as part of the Green Bonds market (NSE, 2019a, 2019b).

Concessional loans

Compared to commercial loans, concessional loans are offered at either a lower interest rate, a longer grace period or a combination of both (OECD, 2003). These funds are guaranteed by the government and made available to state agencies involved in geothermal development. Progress has been noted in that some banks have started participating in some of the early stages of geothermal projects, *e.g.*, African Development Bank (AfDB) and the French Development Agency (AFD), which financed the procurement of drilling rigs for GDC to undertake appraisal and production drilling activities at the Menengai geothermal project. The Italian Development Cooperation also provided funds for exploration drilling of the Menengai project. In addition, Scaling up Renewable Energy Program in Low Income Countries (SREP) funding was also used for drilling at Menengai. SREP funds have been committed for early stage activities in several other countries, including in Tanzania (GDI, 2018).

In Kenya, later stages of geothermal projects (production drilling and power plant construction) have been financed by the European Investment Bank (EIB), Kreditanstalt Für Wiederaufbau (KfW), the World Bank, Japan International Cooperation Agency (JICA), AfDB, AFD, IDA, and European Bank for Reconstruction and Development (EBRD).

These same development partners are active in Ethiopia, where the World Bank and JICA are financing appraisal and production drilling at Aluto-Langano, while AFD is financing appraisal drilling in Tendaho geothermal fields. In Djibouti, the World Bank is financing exploration and appraisal drilling at Gale-Le-Koma prospect.

Furthermore, the drilling of production wells in the Fialé geothermal sites (northern part of Lake Asal) is financed by the Djibouti government and seven financial partners: the African Development Fund (ADF), the Sustainable Energy Fund for Africa (SEFA), the IDA, and the GEF and the ESMAP (both through the World Bank), the AFD and the Organization of Petroleum Exporting Country Funds for International Development (OFID).

In Gale-Le-Koma, ODDEG secured funding from the Arab Fund for Economic and Social Development and Kuwait Fund for Arab Economic Development to develop eight production and two injection wells. Climate Finance (including Climate Investment Fund [CIF] and carbon finance) plays a significant role in the development of geothermal energy, and many developers are planning to incorporate Clean Technology Fund (CTF) in the financing plans. In this regard, TMGO secured a USD 10 million concessional loan from CTF in 2020, which would contribute to the development of a 50 MWe project (Takouleu, 2020).

Blended finance

Blended finance refers to the "strategic use of development finance and philanthropic funds to mobilise private capital flows to emerging and frontier markets", leading to benefits for both investors and local communities. According to the IFC, the term refers to a financing package composed of concessional funding provided by development partners and commercial finance provided by co-investors (IFC, 2017).

Blended finance acts as a catalyst to attract commercial financing in projects with a significant impact on the population (Samans, 2016). Private investors that are normally too risk averse to invest in emerging markets will find comfort in the fact that public institutions that have a privileged connection with the government participate in the project, and they trust that these will resolve any government-related issue that the project may face. As a consequence, their risk premium will be lower and the project may become sustainable.

The public institution can be a shareholder, a lender or a provider of risk mitigation. In most cases, it will have "preferred creditor status" that gives it recourse to the government if the project fails due to government action (or inaction). In this context, it is worth highlighting that blended finance is intended to complement rather than replace official development assistance. One example of blended finance applied to geothermal energy is the partial risk guarantee that AfDB has provided to the IPPs in Menengai, Kenya. This instrument, backed by the government, is intended to address this creditworthiness risk in case the off-taker (KPLC) does not honour payment, or a stem field developer (GDC) fails to supply (adequate) steam (Akker, 2018).

Grants for technical assistance and resource risk- sharing

Grants have been particularly important in catalysing the development of geothermal resources in the East African Rift region. They have been used to support surface studies and exploration drilling and, in some cases, the appraisal and production drilling phases of the projects.

Grants are often part of technical assistance programmes and/or risk mitigation schemes that have been put together by development institutions. For example, early geothermal reconnaissance in Ethiopia and developments in Kenya were financed through grants by the United Nations Development Programme (UNDP) in collaboration with other organisations and the host governments as co-financiers.

UNDP and the Italian government funded surface studies for geothermal resources in Ethiopia, Djibouti and Kenya between 1973 and 1988 (Geotermica Italiana, 1988). UNDP as a grant provider and the World Bank as a lender provided funds for the drilling of appraisal and production wells at Olkaria geothermal field from 1973 to 1980. This culminated in the successful development of the 45 MWe Olkaria I power project.

A more recent instance of UNDP involvement in geothermal projects is the financing of detailed surface studies of the Karthala geothermal prospect in Comoros in 2015.

The currently best-known grant programme in eastern Africa is the GRMF. This is managed by the Regional Geothermal Coordination Unit (RGCU) under the auspices of the African Union Commission (AUC). The GRMF is supported financially by the German Federal Ministry for Economic Cooperation and Development (BMZ), the EU-Africa Infrastructure Trust Fund via KfW, and the United Kingdom Department for International Development (DFID). The facility was initiated in 2012 with the aim of mobilising finance to attract public and private geothermal developers in eastern Africa.

Typically, the grants may cover 20% of eligible infrastructure costs, 80% of eligible surface studies costs and 40% of eligible drilling costs (GRMF, 2018). Furthermore, GRMF covers (under its financial scheme, which is called Continuation Premium) up to 30% of the drilling and testing programme in case developers wish to continue with additional drilling. Funding from the continuation premium depends on availability of funds, however.

According to the GRMF regulations of August 2017, the latter component may cover:

- **a)** up to three full-size reservoir wells (≥ 5″ diameter of the last casing or liner) or
- **b)** a combination of up to three slim hole wells (< 5″ diameter of last casing or liner) and one full-size reservoir confirmation well; or
- **c)** a combination of up to two slim holes and two full-size reservoir confirmation wells.

The fund had a total of USD 115 million for exploration and drilling grants. The 11 countries eligible are: Burundi, Comoros, DRC, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Uganda, Tanzania and Zambia. In 2020, Somalia was officially admitted to the GRMF eligible country list, while other countries – including Mozambique and Sudan, which are not currently eligible for financing – have submitted applications for the grant and may become eligible in the future. By May 2018 (AUC, 2018) the scheme had awarded grants to five countries with 25 projects considered totalling USD 90 452 969 for surface studies and drilling projects (Table 4).

The Geothermal Risk Mitigation Facility aims to support initial site exploration confirmatory drilling to mobilise broader finance for public and private geothermal development in Eastern Africa.

Table 4: Grants awarded for geothermal projects by GRMF

Country	Project	Application round	Amount of grant (in USD 1 000)	Total (in USD 1 000)
Comoros	Karthala	AR2, AR3	845; 10 871	11 716
Djibouti	Arta	AR3	832	832
Ethiopia	Dofan, Corbetti, Fantale, Tulu Moye, Butajira, Fantale, Abaya, Alalobeda; Wondo Ganet, Boku, Daguna Fango	AR1, AR1, AR2, AR2, AR3, AR3, AR4, AR4, AR4, AR4, AR4	977; 7 994; 857; 1 314; 609; 5 407; 1 377; 8 294; 4 125; 5 161; 4 543	40 658
Kenya	Silali, Longonot, Akiira, Barrier, Korosi, Paka, Chepchuk, Arus, Homa Hills	AR1, AR1, AR2, AR3, AR3, AR3, AR4, AR4, AR4	6 027; 8 437; 3 311; 981; 6 213; 6 862; 586; 449; 720	33 586
Tanzania	Ngozi	AR4	3 661	3 661
				90 453

Note: AR = application round.

Source: AUC (2018)

During the fifth application round for GRMF financing, four surface studies and three drilling programmes from three countries qualified for funding. They included surface studies in Buranga, Kibiro and Panyimur in Uganda and Natron SS in Tanzania, and drilling programmes in Dofan and Tulu Moye in Ethiopia and Keijo-Mbaka in Tanzania. The cumulative GRMF support for the seven projects was approximately USD 28 million. As of May 2020, GRMF is in the sixth application round.

Yet, only about USD 6 million of these funds has been utilised so far, according to the AUC. This is because some of the projects awarded grants have not commenced activities as per the grant terms. Reasons for the lag in project progress include interlinked factors such as difficulties in securing geothermal licenses by developers, difficulties in closing PPAs, inability to raise the required counterpart funding, lack of technical capacity to implement the projects, and difficulties in managing the environmental and social impact of the projects.

GRMF is addressing these challenges by having consultative meetings with relevant ministries in different countries, *e.g.* in Kenya, Ethiopia and Tanzania. A planned review of the process of implementing the next rounds of GRMF funding (GRMF 2.0) will be preceded by identifying the needs for each country and recommending the scope for this phase.

Development partners have expressed strong interest in supporting geothermal projects in the region through technical assistance.

The readily available technical assistance programmes in the region are for resource assessment, capacity building, community engagement and development of strategies by governments. In addition, a number of international programmes have provided i) technical assistance to ensure that prospects are de-risked through support to develop conceptual models and review results of exploration studies and ii) support to the governments in the development of legal and regulatory instruments that allow for easy entry of private sector players (Table 5).

Most of the support programmes, however, do not support direct use projects at the moment, with the exception of ARGeo-UN Environment, DFID, USAID, and Icelandic International Development Agency (ICEIDA) (see Chapter 6 for further details).

Table 5: List of development partners/technical support programmes in EARS countries

	Development partner/technical assistance scheme	References
1	**USAID/Power Africa**	www.usaid.gov/powerafrica
2	**Iceland-MFA (ICEIDA) and Nordic Development Fund (NDF)**	www.government.is/news/article/2016/01/12/ICEDIAs-activities-transferred-to-the-Ministry-for-Foreign-Affairs/ and www.ndf.fi/
3	**East Africa Geothermal Energy Facility (EAGER), UK**	http://theargeo.org/fullpapers/C7/Advancing%20Geothermal%20Development%20in%20East%20Africa%20EAGER-converted.pdf
4	**UN Environment**	http://theargeo.org/
5	**BGR, Germany**	www.bgr.bund.de/EN/Themen/Nutzung_tieferer_Untergrund_CO2Speicherung/Projekte/Geothermie/Laufend/TZ_Ostafrika_en.html?nn=8022522
6	**Italian Development Cooperation**	www.aics.gov.it/
7	**Japan International Cooperation Agency (JICA)**	www.jica.go.jp/english/
8	**New Zealand Africa Geothermal facility**	https://nz-agf.org/
9	**Climate Technology Centre and Network (CTCN)**	www.ctc-n.org/news/new-ctcnunido-call-proposals-applications-and-technologies-geothermal-systems-6-african

5.3 Innovative financing to address gaps

Stakeholders involved in the consultation process to develop this study indicated that existing direct finance and risk mitigation options available in the region – for example, from the GRMF – have played a major role in supporting geothermal development and attracting investors to the region. However, several experts pointed out the need for additional risk mitigation support.

Equity and other funding for appraisal drilling, together with public-private well-productivity insurance schemes, have been indicated as possible options to further encourage private sector involvement and facilitate the successful development of geothermal projects, including from low- and medium-temperature systems.

Box 7 shows examples of innovative financial mechanisms for geothermal energy in the region, including the multi-donor InfraCo Africa facility, an example of blended finance which provides equity financing in Ethiopia as well as a public-private well-productivity risk insurance component.

Public-private resource risk insurance schemes, together with complementary investment and operating aid, have been instrumental in supporting the market uptake of geothermal heating projects in France and the Netherlands.

Box 7: Examples of innovative financing instruments for geothermal projects in eastern Africa

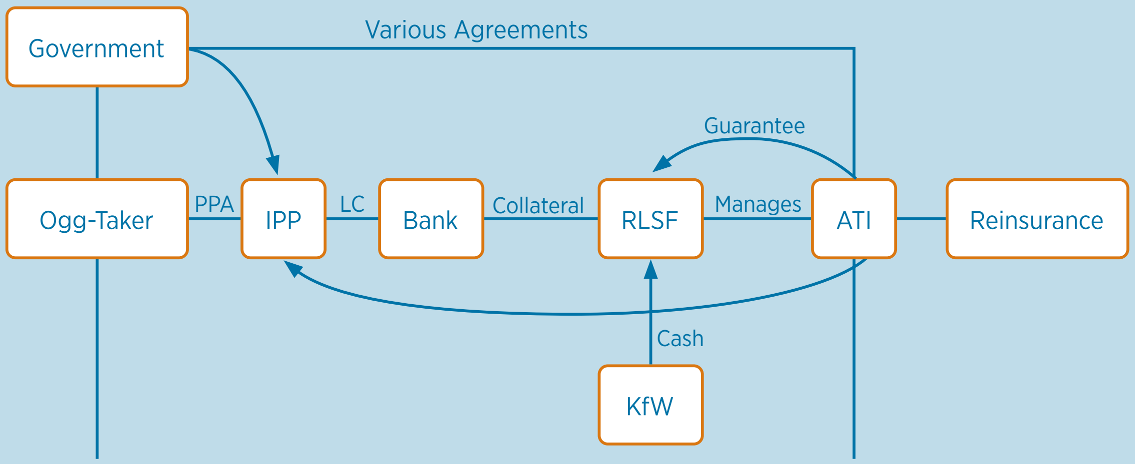
InfraCo Africa: Equity through multi-donor scheme

InfraCo is currently participating in the first phase of Corbetti Geothermal development in Ethiopia which entails drilling of exploration wells and the development of a 150 MWe power plant. In 2015, InfraCo Africa partnered with Berkeley Energy, Africa Renewable Energy Fund, Iceland Drilling and Reykjavik Geothermal, the developers of the Corbetti Geothermal project, to provide project risk capital in the form of equity funding of up to USD 15 million. This amount was later revised upwards to USD 30 million in 2018, with USD 25 million being committed as equity finance and the remaining USD 5 million as standby equity. Besides equity financing, InfraCo Africa is also providing project management, technical expertise to optimise well siting, insurance in geothermal exploration drilling as well as best practices in environmental, social and safety management of the project (InfraCo Africa, 2018).

Regional Liquidity Support Facility

The Regional Liquidity Support Facility guarantees the IPPs a normal revenue of up to six months in case the off-taker does not pay on time. It was developed by the German Development Bank (KfW) with the multilateral insurer African Trade Insurance (ATI). In this scheme, a commercial bank issues a prior letter of credit to the IPP that can be executed 15 days after the due date of the original invoice to the utility. The letter of credit (LC) is issued against a guarantee of EUR 32 million cash collateral that has been provided by the German government through KfW and an on-demand guarantee for the same amount that is provided by ATI that has an A rating from S&P (ATI, 2020). This way, the IPP can reduce the Debt Service Reserve Account (DSRA) it normally needs to prove that it can still service the debt in case of non-payment (Figure 44). The provision of this type of guarantee was historically the responsibility of the off-taker. Still, most were not in a position to source the LC and projects were unable to reach financial close.

Figure 44: Regional Liquidity Support Facility scheme



Source: African Trade Insurance Agency

GeoFutures Investment Fund

GeoFutures Investment Fund is an investment scheme developed by Parhellion Underwiting, Inc., with support from Power Africa, to provide grants and geothermal drilling cost indemnity insurance for projects in the eastern Africa region to support an initial portfolio of 8-12 projects with a combined potential of 600 MWe (Parhelion Underwriting Ltd, 2019). For a relatively small premium, paid by the public sector to the scheme, the risk associated with declining well productivity is transferred to the private sector. The scheme was developed to complement other similar mechanisms in the region by providing funding for early stage geothermal exploration and well productivity insurance-backed guarantee.

An initial proposal for the scheme provided for three pillars designed to offer support for the project at different stages (Robertson-Tait *et al.*, 2017).

a) Technical assistance – offers 100% grants for supporting enabling frameworks for geothermal development.

b) Direct finance – offers 40% of eligible cost for surface exploration and well citing (grants), infrastructure development (convertible loans), and exploration drilling (grants).

c) Risk mitigation – offers 60% of well productivity insurance cost to the private sector.

In addition, the scheme may provide financing for the construction of the power plants and incorporates an environmental and social management system that ensures protection for the environment and social systems as well as the welfare of employees by advocating for the use of best practices.

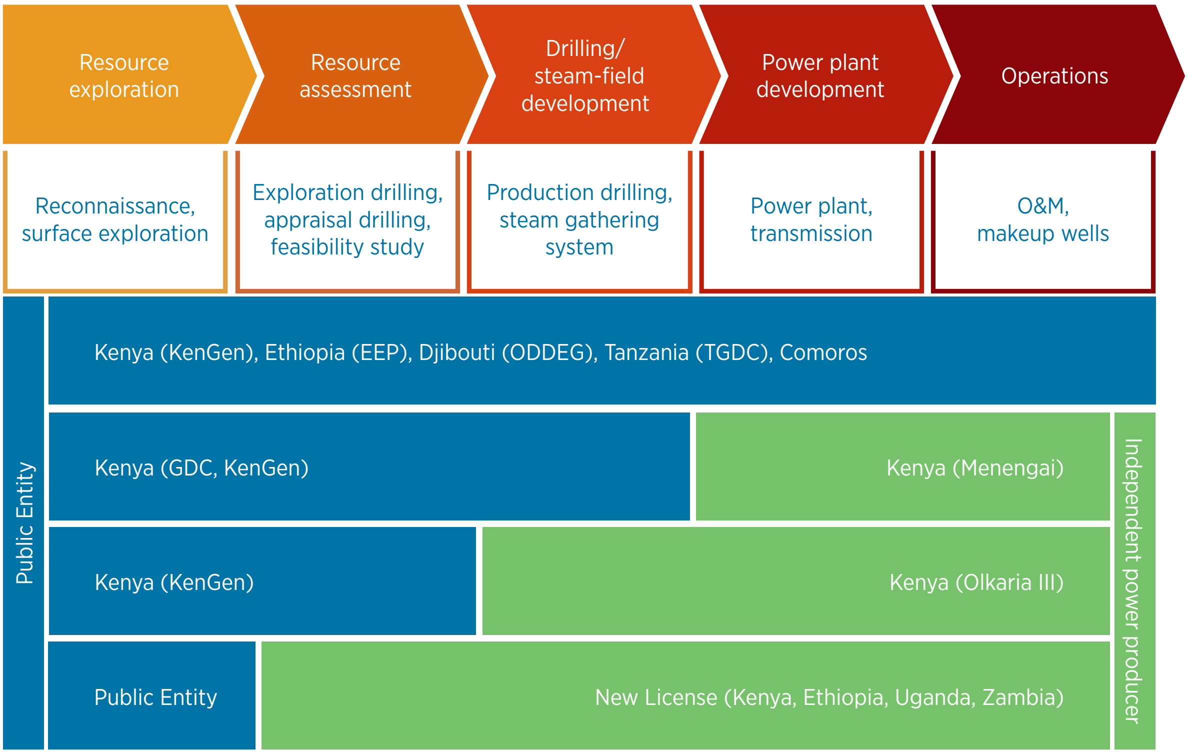
In May 2020, the fund received a USD 1 million scale-up grant and partnership from the national Danish Partnering for Green Growth and Global Goals 2030 Initiative (P4G). The grant will enable the fund to mobilise insurance underwriting capital to de-risk sustainable investment opportunities through a blended finance platform (Parhelion, 2020). As of May 2020, the facility was under development. The fund managers reported that the delay in the operationalisation of the fund was due to limited institutional resources of some accredited entities and a time-consuming process for obtaining no-objection letters from beneficiary countries (interview with Parhelion, 2019).

5.4 Geothermal development models

As analysed in the previous sections, most of the EARS countries are currently involved in early stage geothermal development, mostly using public funds to confirm resource occurrence, type and quality before inviting private sector participation. This approach is credited with helping to reduce risks and keeping tariffs low.

In Kenya and Ethiopia, however, which have the most advanced geothermal developments, the geothermal sector is being liberalised such that private investors can participate in all stages of geothermal development, resulting in a wide range of possible development models as depicted in Figure 45.

Figure 45: Geothermal development models in the East African Rift region



Note: O&M = operation and maintenance.
Based on: GDC (2017b)

Public development model

This model is implemented either by the government directly or through a state agency as a developer. The state agencies are either wholly owned by the governments as vertically integrated entities – *e.g.*, EEP of Ethiopia and TGDC, a subsidiary of TANESCO in Tanzania – or unbundled state-owned vertically splitting entities, *e.g.*, KenGen of Kenya, which is partially private, and GDC, which is 100% state-owned by the government of Kenya.

In this model, the governments provide direct financing of the geothermal projects and access concessionary finance from bilateral and multilateral banks for downstream stages of the projects. The exploration phase is usually covered by funds from the governments and grants from international support programmes, while the downstream phases are usually financed from project finance and concessionary loans.

The initial phases of geothermal projects require the use of locally available equipment during exploration studies. This includes geological, geophysical and geochemical field and laboratory equipment and in some cases drilling rigs.

In recent years, countries have acquired some geochemistry sampling and analysis equipment and MT/TEM geophysical equipment through support from UN Environment ARGeo programme. However, there has been collaboration between countries for the use of high-tech equipment and experienced personnel that are not readily available in all countries.

The services have been offered by KenGen and GDC of Kenya and TGDC of Tanzania. Djibouti, Ethiopia and Kenya have acquired drilling rigs to be used for both exploration and production well drilling.

However, acquisition of the high capacity drilling rigs by countries may not be recommended during the exploration stages but could be considered during the subsequent phases to help lower the cost of drilling.

Private development model

The private development model involves licensing of a geothermal greenfield to IPPs under a build-own-operate (BOO) or build-own-operate-transfer (BOOT) scheme. In this model, IPPs are expected to undertake all the stages of geothermal development, from carrying out surface studies to the construction and operation of the power plant for the duration of the PPA, and in the case of BOO projects, within stipulated timelines. For BOOT projects such as Corbetti and Tulu Moye in Ethiopia, the power plant and operation thereof is transferred over to the government of Ethiopia after the duration of the PPA.

The developer will only be required to pay ground rental fee or compensation to the government as per the law. Several greenfields have been licensed to IPPs in Ethiopia, Kenya, Uganda and Zambia. Conditions for licensing are that the licensee is expected to have adequate financial and technical capacity to undertake the project through the lifetime of the project.

Public-private partnership (PPP) model

The PPP model involves both private and public sectors. In this case, an IPP enters into an agreement with the state or a state agency for the development of the prospect or field according to the licensing conditions. The PPP model has many variations starting from post drilling of exploration wells to post field development, as described in Figure 45. Two of the PPP models have been used in Kenya as described below.

PPP Model 1

In this case, an IPP enters into an agreement with the state or a state agency for the development of the field after a successful exploration and/or appraisal drilling campaign undertaken by a government agency. The licensee would, therefore, drill appraisal and production wells, construct a power plant and undertake O&M under a BOO scheme. This model was used to license OrPower 4 Inc. for the Olkaria III geothermal project in Kenya.

PPP (PISSA) Model 2

Project Implementation and Steam Supply Agreement (PISSA) is a PPP model in which a government or state agency develops a steamfield and sells steam to an IPP to convert to electricity, *e.g.*, the Menengai project in Kenya where GDC is the steam supplier and IPPs are the generators. An alternative is that both the steam supplier and generator could be private companies. This model is favoured by some IPPs that are reluctant to take risks of early stage exploration and drilling.

PPP (Ethiopia) Model 3

In this case, an IPP enters into an agreement with the state or a state agency for the development of the field. The licensee would drill exploration and production wells, construct a power plant and undertake O&M under a BOOT scheme. Transfer of knowledge and property is prepared and at the end of the PPA the power plant is transferred over to the state or state agency according to terms set forward in the PPA and IA. This model, which is being used in the Corbetti and Tulu Moye projects in Ethiopia, allows the state or state agency to adjust the tariff by adjusting the length of the PPA term, since the transfer mechanism is predetermined in the PPA and IA.

5.5 Lessons learned and perspectives

Discussion of the financing options, including risk-mitigation schemes, and of development models that have been used in the region has made clear that the selection of a business model is not a definitive or static decision. Different models may be deployed within a single country or even a single concession area. The selection of a business model may be influenced by several assumptions, and each model presents various risks. Due to the long development period of geothermal projects, those assumptions and risks may change, and accordingly, decisions about which business model to deploy may change as well. Table 6 presents a SWOT (strengths, weaknesses, opportunities, threats) analysis of the various business models.

> Kenya and Ethiopia have opened all stages of geothermal development to private investment, creating possibilities for a wide range of development models.

Table 6: SWOT analysis of the business models

	Public	PPP	Private
Strengths	1. Government funding thus low cost of development 2. Concessionary loans guaranteed by the government 3. Early stage financing possible through higher government risk 4. Local expertise available for some countries	1. Cost sharing between governments and private investor making development quicker 2. Fast financial close as project is significantly de-risked 3. Expertise used at various stages have best resource allocation	1. Quick decision making 2. Finance can be raised from non-traditional sources 3. Experts from the international market 4. Reduction of the funding needs of the government or utility
Weaknesses	1. Borrowing depends on countries' debt situation 2. Competing funds with other government programmes 3. Inadequate special skills 4. Use of public funds that would be used for other public investments. 5. Slow decision making 6. Risk of corruption and embezzlement of public funds	1. Project financing can take time to reach financial close 2. Duplication of efforts for some stages of exploration	1. Project financing can take time to reach financial close 2. Some private companies do not have adequately trained experts 3. Availability of low-cost funding in early development
Opportunities	1. Early stage exploration and opening up of geothermal projects	1. Development of geothermal projects after significant risk reduction by government	1. Investment in greenfields or brownfields
Threats	1. Lack of adequate and regular development funds	1. High risk may be experienced if risk allocation is not well done	1. Government regulatory environment may change

The public development model utilises funds from the exchequer and concessional loans that have low interest rates during the high-risk early phase. This avoids expensive equity financing, which would be required in the case of the private development model. However, given the numerous government programmes that compete for public resources, the private model could have access to more reliable and unconventional sources of capital, with predictable disbursement, unlike the public model.

On the other hand, the PPP model stands to benefit from co-sharing of risks and costs between the public and the private sector, resulting in significantly de-risked projects which can attract more financing from the debt market at favourable rates.

Whereas the public model has the potential for least expensive development, a PPP model has the potential for delivering projects in the shortest time and most efficient manner. This is because it has access to the benefits of both the public and the private models such as a de-risked project at a relatively lower cost and access to international pools of experts. However, complexity in negotiations for partnership and financing in the PPP model can result in significant delays.

Recent developments with Corbetti and Tulu Moye projects in Ethiopia suggest that, with the current risk mitigation mechanisms and when stable PPAs and policies are put in place, the early involvement of private developers in greenfield geothermal projects may be a successful option in the region.

In addition, stakeholders who took part in the consultation process for this report pointed out a number of ways to improve the financial viability of geothermal projects. The first option is the co-location of power projects and direct use projects, which can bring in extra revenue (see Chapter 6 for more details).

A second option is for power developers to consider early generation using wellhead technology, as this has the benefit of early revenue generation to offset some future costs as well as allowing the testing of the performance of the geothermal reservoir, hence reducing the risk of a project.

Based on the data acquired from a geothermal field during early electricity generation, it is also possible to facilitate access to finance. This is because such data are useful in improving the level of confidence in estimating the potentially recoverable resource, as applied in the United Nations Framework Classification for Resources UNFC-2009 geothermal specifications.

The UNFC-2009 geothermal specifications were developed by the International Geothermal Association (IGA), together with partners, as a common universally accepted framework for estimating geothermal potential while ensuring transparency and comparability with other energy resources and projects in different countries (IGA and UNECE, 2016) (Box 8).

One of the metrics used in this framework is the maturity of resource assessment, which is in turn dependent on the availability of quality data.

Stable policies and PPAs can help to attract private investors at the early stages of geothermal projects

Box 8: UNFC classification of geothermal resources

The United Nations Framework Classification for Resources (UNFC) provides a principle-based methodology for reporting geothermal resource estimates based on three fundamental criteria: degree of favourability of the economic and social conditions; maturity of resource assessment and commitments for project implementation; and the level of confidence in the estimate of the potentially recoverable resource. These are represented using a numerical coding system on a three-dimensional grid consisting of E-axis, F-axis and G-axis respectively. The numerical coding system takes into consideration the level of geological knowledge, the stage of resource assessment, and advancement in socio-economic and regulatory conditions affecting the project.

The geothermal resources classified according to the UNFC-2009 specifications for geothermal resources can be compared with other energy resources or other projects in different countries. The transparency and comparability of this standardised method towards geothermal resource estimates would lead to a concrete value proposition to investors, as it would support decision making on investment options.

Source: IGA and UNECE (2016)

Phased development of geothermal projects could also help to unlock financing. As an example, the Olkaria geothermal field was subdivided into seven blocks for development: Olkaria East, Olkaria Northeast, Olkaria Central, Olkaria Northwest, Olkaria Southwest, Olkaria Southeast, and Olkaria Domes. These blocks were explored separately and subsequently Olkaria power plants I, II, III, IV and V were developed (Box 9). In Menengai, GDC is developing the field in two phases: the first phase of 105 MWe involved three units of 35 MWe each, while the second phase will be for 60 MWe. Likewise, in Ethiopia, the Tulu Moye Geothermal Operations and the Corbetti Geothermal Limited plan to develop the respective geothermal fields in stages, starting with a power plant of 50 MWe based on about 11 geothermal wells to prove the viability of the resource and test the practicability of the PPA. The second phase will involve the development of a 100 MWe power plant, expanding the total generation to 150 MWe for each field (RG, 2020, 2017).

Box 9: Phased development of Olkaria geothermal power plants

As indicated in Table 2, Olkaria I was initially implemented in three phases of 15 MWe each, with the first 15 MWe unit being commissioned in June 1981, the second 15 MWe unit in November 1982 and final 15 MWe unit in March 1985 in the Olkaria East block. Subsequent developments at the Olkaria I field included 2 x 75 MWe Olkaria I Additional Units (Olkaria I AU) commissioned in 2014 and 38.3 MWe wellhead units that were commissioned between 2011 and 2014. In the Olkaria Northeast block, Olkaria II, a power plant with a capacity of 2 x 35 MWe, was commissioned in 2003, and subsequently, an additional 35 MWe was commissioned in 2010.

Photograph 7: Olkaria geothermal power plant

Photo credit: KenGen

Additional drilling is being undertaken in the field for future power plants. The Olkaria III power plant, owned and operated by a subsidiary of Ormat International (OrPower 4 Inc.), is located in Olkaria Southwest field. It has a total installed capacity of 170 MWe, commissioned between 2000 and 2019. Exploration drilling was undertaken in Olkaria IV (Olkaria Domes) between 1998 and 2000, which led to drilling of appraisal and production wells from 2006. The first power plants in the field were 42.8 MWe wellhead units commissioned between 2013 and 2015. The main power plant of 2 x 75 MWe was commissioned in 2014. The 172.3 MWe Olkaria V power plant, commissioned in July and September 2019, is located in the Olkaria Domes.

6.

6. ENABLING UPTAKE OF DIRECT USE APPLICATIONS

Direct use is the most efficient utilisation of the geothermal resource because the energy is used *in situ* without conversion to electrical energy.

The majority of geothermal direct use applications utilise resources in the low- to moderate-temperature range of <150°C. Steam and residual heat from high-temperature utilisation can also be used in direct use applications, however.

Given these factors, this chapter analyses the challenges facing geothermal direct use in the East Africa Rift region and proposes actions to enable its market uptake. The increasing interest in direct use applications was captured in the Kigali Statement, which was the main outcome of the seventh African Rift Geothermal Conference (ARGEO-C7), which called for the mainstreaming of direct use in geothermal development in Africa.

6.1 Quantifying potential and benefits

The main objective of geothermal developers in the countries of the EARS has been predominantly electricity generation from high-temperature fields. However, the high-temperature resources occur only in isolated places which have central volcanos, and within only a few countries of the eastern branch of EARS.

On the other hand, occurrences of low- to medium-temperature resources are more common as these occur within large sections of the rift floor between the central volcanoes. These resources usually have temperatures <150°C and manifest mainly in the form of hot springs. They are conducive for direct use as well as electricity generation using binary technologies (see Box 1).

The technical workshop on the Geologic Development and Geophysics of the Western Branch of the Greater East African Region, organised in 2016 by UNEP-ARGeo, concluded that most of the geothermal resources in the western branch are low- to medium temperature and suitable for direct use applications.

In some areas, steam is available near the surface from shallow geothermal systems, and it can potentially be developed for local direct uses and domestic water production. Direct use project developments benefitting from the shallow resources available along the EARS, however, still require customisation in terms of geo-scientific exploration approaches and socio-economic approaches and should be adjusted to the local situation (Onyango and Varet, 2014).

The abundance of low- to medium-temperature geothermal resources in the region has created large potential for direct use for agricultural and industrial applications. If well implemented, direct use of geothermal could support industrialisation and transform the countries of the region from a socio-economic development perspective, as exemplified by the Geothermal Resource Park in Iceland (Box 10).

Box 10: Geothermal energy as a driver for economic transformation: Case study of Geothermal Resource Park in Iceland

Iceland is a pioneer in the direct use of geothermal energy. Geothermal energy has contributed significantly in transforming Iceland from one of the poorest countries in Europe to one of the most prosperous in the world. Iceland utilises around 171 petajoules (PJ) of geothermal energy annually, the equivalent to having almost 6 000 MWe installed. The Geothermal Resource Park in Iceland is a clear example of the correlation between geothermal development and local economic benefits.

The Resource Park

The Geothermal Resource Park is located in the Southern Peninsula (Suðurnes region) of Iceland. Two power plants owned and operated by HS Orka hf are located at Svartsengi (74 MWe, 190 MWth) and Reykjanes (100 MWe). The Svartsengi power plant was the first geothermal CHP installation in the world when it was commissioned in 1974. Reykjanes power plant was commissioned in 2006. The area of the two power plants constitutes what is now known as the Reykjanes Geothermal Resource Park (HS Orka, 2019).

The Geothermal Resource Park hosts several companies that are unique in many ways but share common characteristics and are driven by a common source of energy. The companies use green electricity and by-products of geothermal electricity generation from Svartsengi power plant.

Utilisation of geothermal energy in the resource park presents several advantages. When the energy is used for electricity, users benefit from a high-quality supply because they are directly connected to the generation source with no voltage interruptions and minimal frequency variations. This improves quality, as well as the efficiency of electricity supply, permitting users to have complete flexibility in their operation with minimal unplanned downtime concerns. Bypassing the grid provides energy savings, as administrative costs and technical losses experienced through grid supply are eliminated.

The customers in the resource park enjoy further lower energy costs for heat because of the benefit of having shared infrastructure costs. This is because the costs incurred by the developer in supplying the energy are shared by all the customers. Therefore, the service costs less simply because the provider of the infrastructure is supplying numerous customers in the same location.

The resource park approach presents an opportunity for the developer to create other revenue streams. These revenue streams come from utilising the by-products of electricity generation, such as excess geothermal steam, brine, condensate, carbon dioxide, silica and hydrogen sulphide.

Iceland's resource park was developed with the objective of minimising waste. Using the principle of "industrial symbiosis", the customers in the resource park are selected so as to facilitate exchange of materials and energy among themselves. Through this principle, the waste of one customer becomes the raw material for the next customer. A biofuel firm located at the resource park, for example, utilises the carbon dioxide emitted by the geothermal power plant to manufacture methanol, which is blended with petrol to power cars. Similarly, customers can exchange energy through cascaded use. The geothermal resource park's zero waste concept thereby reduces production costs and improves tenants' competitiveness.

Direct use applications

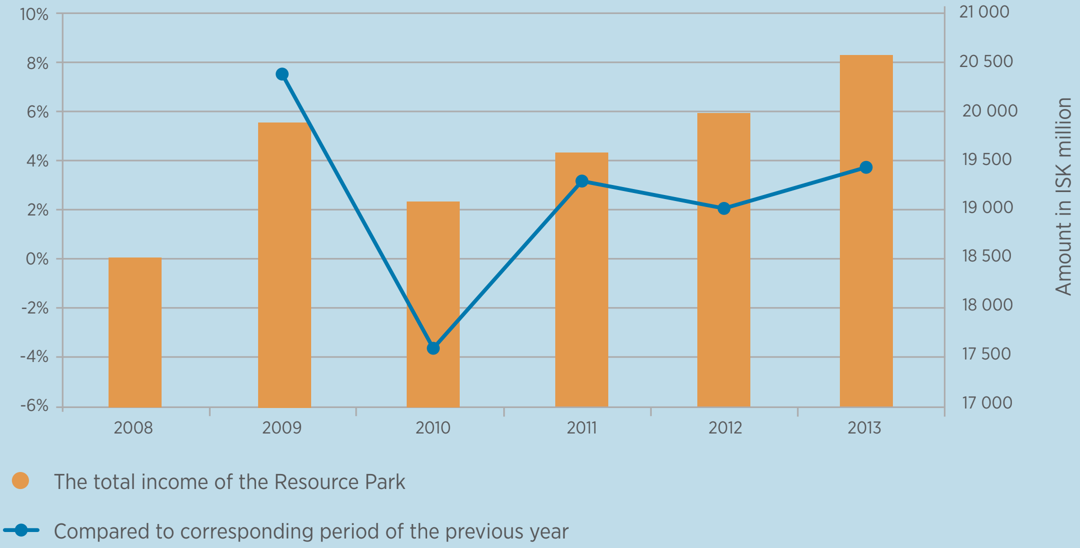
A subsidiary company of HS Orka, HS Veitur hf, utilises the geothermal resource to provide district heating and hot water for domestic use in neighbouring municipalities. Other direct use applications located in the resource park include the production of methanol from geothermal carbon dioxide for blending with gasoline and a molecular farming facility. The Blue Lagoon facility – a high-end geothermal spa – is the best-known customer in the resource park and one of the top tourist attractions in Iceland. It receives approximately 1.5 million visitors annually and generated about USD 114 million in revenue in 2018. A dermatological clinic is also located at the Blue Lagoon to treat skin disorders with natural products made using silica extracts from the geothermal brine. In addition, there is algae and sea weed farming, fish farming, fish drying, production of cod liver oil, production of collagen from fish, production of enzymes and eco-friendly cosmetics.

Photograph 8: Blue lagoon in Iceland

Economic benefits

In 2013, the nine companies located in the resource park had a combined income of ISK (Icelandic krona) 20.5 billion (around USD 165 million), which amounted to 1% of Iceland's GDP that year (Figure 46). In the period 2008-2013, when the Icelandic economy shrank by 1.7%, the value of the nine companies located in the resource park grew by over 21%. During the same period, the added value of the Icelandic economy as a whole decreased by 1.7% in real terms. Income generated by activities other than electricity generation in the park represented 65% of the total revenue in 2013.

Figure 46: Total income of the Geothermal Resource Park companies (2008-2013)



Source: Gamma

Geothermal energy has a significant impact on the attractiveness of Iceland as a tourist destination, with over 60% of all visitors enjoying one of the geothermal spas in Iceland and 25% of the visitors mentioning geysers or geothermal areas as influencing factors in visiting Iceland.

In terms of employment, the Svartsengi power plant employs about 60 staff and the Blue Lagoon employs over 700 staff. The combined direct use facilities in the resource park employ more than 1 600 people. Employees in the region's geothermal industry reportedly earn 30% higher remuneration than the average in Iceland. The combined income of all the companies at the resource park exceeded USD 2 billion in 2016, which amounted to 1% of Iceland's GDP (Oladottir, 2019).

Lessons from the Geothermal Resource Park:

- Development of a resource park requires the participation of both the public and private sectors as well as the local communities. The public sector is required to participate in industrial zone planning, licensing and marketing of the available opportunities at the park.
- An established geothermal resource park should support research and innovation to allow for inventions and the continuous development of new products from the geothermal resource. High-tech companies and start-ups are encouraged to explore opportunities in the geothermal industry.
- Utilising both electricity and heat is the most environmentally friendly and efficient use of the geothermal resource. This approach has great potential to transform economies of countries and to help in meeting several sustainable development goals. As demonstrated by the resource park approach, higher financial returns as well as more employment opportunities are generated when power generation is combined with direct uses.
- Economic risk is lower due to the multiple revenue streams involved in this approach, which can result in better project bankability. Other risks, such as technical risk, can be further reduced through continuous research and development.

Direct use of geothermal could support industrialisation and transform the countries of the region from a socio-economic development perspective, as exemplified by the Geothermal Resource Park in Iceland

6.2 Key success factors for direct use development

Policy and regulatory frameworks

Analysis of the current status in the East African Rift region indicates that no policies exist to guide and regulate direct use developments. There are licensing procedures for direct use in Ethiopia and to some extent in Kenya, but regulations have not been developed in both countries to guide investment in this sector. In Ethiopia, licensing of direct use projects is undertaken separately from power generation and is restricted to resources of up to 120°C (Federal Democratic Republic of Ethiopia, 2016). In Kenya, the Energy Act of 2019 emphasises the power generation aspect of geothermal development while direct use is mentioned as a codevelopment if resource characteristics allow.

Besides the legal and regulatory frameworks, policies and incentives to support the deployment of direct use are lacking in the region. These could include the development of geothermal heat roadmaps with clearly stated targets and fiscal and financial incentives, such as tax breaks and subsidies.

Examples from France, Germany and the Netherlands show that accelerated development of geothermal direct use in those jurisdictions was preceded by the development of enabling policies, regulatory frameworks and supportive incentives. For example, in France, a geological risk guarantee scheme established in the 1970s resulted in the development of many doublets in Paris, which allowed for the implementation of space heating and sanitary hot water production for approximately 250 000 houses between 1976 and 1986.

In the Netherlands, a geothermal action plan envisaged the generation of 11 PJ of geothermal heat by 2020. Furthermore, 5 PJ of geothermal energy per year is earmarked for development and utilisation in horticulture (Box 11).

Mexico developed a roadmap for geothermal heat utilisation which envisaged the growth in installed geothermal direct use capacity from 156 MWt in 2013 to 3 800 MWt by 2030. The roadmap highlights potential direct use applications, barriers to deployment and strategies to overcome the barriers (IRENA, 2019a).

The New Zealand Geothermal Association also published a guide aimed at providing a strategic approach to develop geothermal direct use in New Zealand.Implementation of the strategy is expected to result in an annual increase of 7.5 PJ of geothermal heat usage and employment of an additional 500 people due to the implementation of new projects between 2017 and 2030 (New Zealand Geothermal Association, 2017).

Abundant low- and medium-temperature heat resources give the region major potential for direct use and industrial applications.

Box 11: The role of policies in catalysing geothermal direct use development

The growth of geothermal development in the Netherlands has been impressive in the recent past, with 16 large heating plants and over 50 000 small-scale heating systems in place in 2019. This growth was driven mainly by investors in the greenhouse sector. Some of the success factors for this growth are as follows (IRENA, 2019a):

- **a)** A requirement for the oil and gas operators to make subsurface data available to the public led to a better understanding of the geothermal resource resulting in reduced resource risk.
- **b)** The establishment of a geothermal risk guarantee fund since 2009, through which geothermal developers are compensated 85% of the cost of drilling a well in case of unfavourable well productivity, encouraged accelerated development.
- **c)** The establishment of a renewable heat operating grant in 2012 enabled the payment of a heat feed-in premium to operators of such systems, which was equivalent to the difference between the cost of renewable heat and that of gas.
- **d)** The establishment of a geothermal energy action plan for the Netherlands which aimed to achieve the generation of 11 PJ of geothermal heat by 2020. It also indicates that geothermal energy could meet 5% of total heat demand in the country by 2030 and 23% by 2050.
- **e)** A plan to accelerate the development of geothermal for horticulture set a target of increasing geothermal utilisation in the sector by 5 PJ per year.

As of December 2018, there were 51 geothermal exploration and nine production licenses in the Netherlands with another 20 under processing. Twenty-four geothermal doublets were already drilled, producing a total of approximately 4 PJ of heat (Ministerie van Economische Zaken en Klimaat, 2019).

Increasing awareness of direct use potential and benefits

The lack of policies and enabling regulatory frameworks for direct use in the region is primarily due to the lack of information about the viability and potential of direct use projects. This general lack of awareness can partly be attributed to the limited assessment of direct use potential in the region due to an emphasis on electricity generation by the governments in the region. The lack of emphasis on direct use often results from the fact that most geothermal departments are domiciled in energy ministries, whose main mandate is the generation of electricity. However, this aspect is gradually changing.

Countries in the western branch of EARS, which mainly have low- to medium-temperature resources, are considering developing direct use projects alongside small-size power generation using binary technology (Omenda *et al.*, 2016a). In this regard, Uganda has carried out prefeasibility studies for various direct use applications in combination with electricity generation in the Kibiro and Panyimur geothermal prospects.

Further prefeasibility studies carried out by GDC and USAID revealed that some direct use applications are viable on a commercial scale. Therefore, identifying other applications which can be viable on micro and macro levels using appropriate tools is important (see Chapter 3).

Several geothermal stakeholders in the region recommend that the benefits of direct use, particularly the socio-economic impacts, should be clearly outlined in order to influence decision makers and local communities to support its deployment. However, most of the respondents to the questionnaire conducted in the context of this study indicated a lack of technical capability to undertake such studies. A methodology developed by the UN Food and Agriculture Organisation (FAO) to assess the benefits and the associated costs of deploying sustainable energy solutions in agri-food value chains can be adopted for this purpose (FAO, GIZ, 2019) (Box 12). Other identified measures that would help promote awareness on direct use in the region include sharing of information on successful direct use projects and capacity building on the identification and development of direct use projects.

Box 12: Assessing the impacts of renewable energy intervention in agri-food chains

As part of the Investing in Sustainable Energy Technologies for the Agri-food Sector (INVESTA) project, the FAO and the German International Cooperation Agency (GIZ) developed a methodology for quantifying the impacts of using renewable energy technologies in agri-food value chains. The objective was to promote sustainability in the water-energy-food nexus. This methodology was designed to support decision making by providing crucial information regarding the socio-economic impacts of renewable energy intervention in agri-food value chains.

The methodology, which is a cost-benefit analysis tool, assesses the financial as well the co-benefits (environmental, social and economic) and hidden costs (those not included in the purchase price) of renewable energy interventions in agri-food value chains. It has been applied to assess the impacts of using energy from solar and/or biogas on the milk, rice and vegetable value chains in Kenya, the Philippines, Tanzania and Tunisia.

For each of renewable energy intervention, *e.g.*, the application of solar energy in milk chilling, a set of indicators is selected for assessment. Some of the indicators considered include employment creation, changes in household income, reduction in GHG emissions, reduction in food loss along the value chain, reduction in fossil-fuel consumption, *etc.* Using the results of this assessment, the net socio-economic impacts of the renewable energy intervention are then analysed at a project level and a national level.

Besides the socio-economic impact assessment, the other outcomes of the methodology include the identification of instruments to overcome barriers hindering the adoption and deployment of the renewable energy solutions in the agri-food value chains, such as policy and regulatory instruments, financial instruments to hedge against risks, and delivery business models (FAO and GIZ, 2019). A similar methodology can be adopted to suit other renewable energy sources such as geothermal, albeit with necessary modifications.

In an effort to raise awareness on direct use of geothermal energy, GDC from Kenya developed five direct use demonstration projects in the Menengai geothermal fields using energy from a low-pressure geothermal well. Stakeholders visiting the facility can learn and see how geothermal energy is utilised in aquaculture and greenhouse heating, as well as for milk pasteurisation, drying of cereals and laundry operations (see Chapter 3).

GDC collects data during the operation of the demonstration projects to showcase the technical and financial viability of direct use. Information gathered from successful demonstration projects should be used to promote further investment in direct use.

Alignment with broader development plans

Aligning geothermal development plans with the development plans of other sectors including the industrial sector is crucial to attracting productive activities close to geothermal resource sites. Some non-energy-oriented government agencies are running programmes which could catalyse the demand for geothermal heat; hence the development of direct use projects.

In 2019, for example, the government of Kenya established a special economic zone (SEZ) in Naivasha, near the Olkaria geothermal project. The SEZ created a lot of interest from industries that require heat for their operations, *e.g.*, a textile manufacturer and a beer maker.

Some of the other potential direct use applications which could be developed in the SEZ include agro-processing, post-harvest operations, greenhouse farming, industrial applications and tourism. The companies located within the SEZ would benefit from tax concessions and cheaper geothermal power from the Olkaria geothermal power plants.

In a bid to boost the economic development within their jurisdictions, the local authorities contacted during the development of this study indicated that they are running programmes to support similar industrial initiatives.

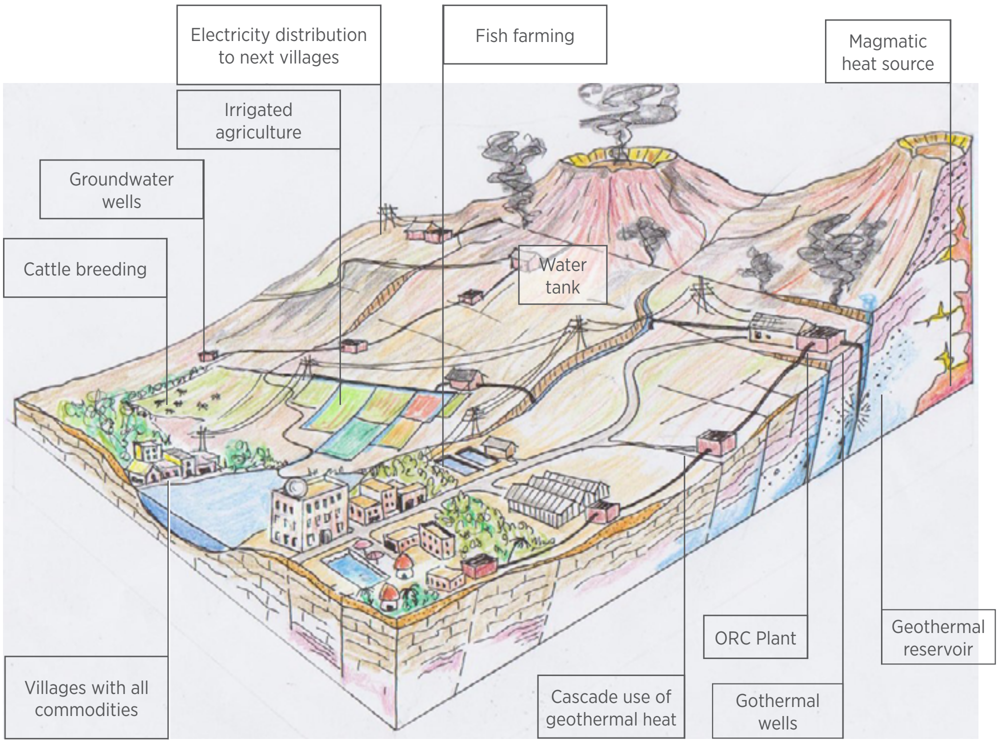
The sources of energy being considered by the local authorities for these initiatives include solar, wood fuel, fossil fuels and electricity; geothermal could also be considered in areas where it is available. Where applicable, the local authorities and geothermal developers in those jurisdictions could consider deepening their collaboration in the implementation of the initiatives. In this regard, the non-energy-oriented entities indicated that their collaboration with the geothermal developers would, among other things, entail awareness creation and mobilisation of industries to utilise geothermal heat, promotion of enabling frameworks through legislative and policy support, and in some cases, co-development of infrastructure for geothermal heat utilisation.

Another strategy that could help the growth of direct use in the continent is to embrace the Geothermal Village concept, in which geothermal resources are used as a catalyst for development and socio-economic transformation of isolated communities (Box 13).

Box 13: Geothermal Village concept

Many geothermal sites are in remote locations where communities lack access to modern sources of energy and basic necessities such as clean water, adequate food, health care and employment. The geothermal resources in these areas, some of them occurring at shallow depths, remain untapped. This is due to a lack of awareness by policy makers, decision makers and financial planners about the benefits geothermal resources could provide. Development of these resources can be done at a low cost and would provide off-grid electricity to communities, as well as heat for direct use applications that could be used to start cottage industries to support the economy of the villages (figure 47) (Varet et.al, 2014).

Figure 47: The model of a geothermal village



Source: Varet *et al.* (2014)

Projects that could be implemented include pumping of water for irrigation, fish farming, greenhouse heating, drying of various agricultural products, process heating, pasteurisation of milk and cold storage, among others. This model is exemplified by the Tuaropaki Trust operation at Mokai in New Zealand, where the community has invested in a geothermal power plant, dairy processing plant, food and nutraceutical operations, and production of industrial products. In Ethiopia, the AGAP, which is a geothermal developer owned by 13 communities living in the Afar region, is considering as a first step the development of a geothermal project for the benefit of about 100 000 people residing in the Teru plains. The project will involve the drilling of geothermal wells down to a depth of 500 m to 1 000 m, development of a 5 MWe power plant and the development of a local electricity grid in the area. In addition, the project will benefit local agro-industrial developments, mainly milk and meat processing (Gardo and Varet, 2018).

Financing strategies

So far, direct use projects in the East African Rift region have not benefited from concessional funding, in spite of the massive potential of the technology. This is partly attributed to lack of awareness and the absence of heat tariffs and heat purchase agreements. Consultation with stakeholders revealed that the difficulty of funding direct use projects is partly attributed to a lack of demonstrable financial viability. Using appropriate tools, the financial and economic viability of direct use projects can be determined and a competitive heat tariff developed – both key enablers for unlocking direct use financing.

Another way to make direct use projects more financially attractive is to develop them alongside power plant projects so that they utilise residual heat from separated brine or energy from low-temperature and low-pressure wells.

Another option is to utilise excess steam that is not used for power generation. This eliminates the need to drill expensive wells specifically for direct use, hence reducing the cost of such projects.

Examples of this include the Olkaria geothermal spa, which utilises separated brine from the Olkaria II power project; the Oserian greenhouse heating project, which utilises a cyclic geothermal well that is not conducive for power generation; and the Menengai direct use demonstration projects, which utilise a low-pressure well. Around the world, examples of co-development of power and direct use are the Geothermal Resource Park in Iceland (HS Orka, 2019) (see Box 10) and Ngawha Innovation and Enterprise Park, under development in New Zealand (Ngawha Innovation and Enterprise Park, 2019).

Photograph 9: Olkaria geothermal spa

Photo credit: KenGen

In an effort to support the development of low-medium enthalpy geothermal resources, GRMF has indicated it is developing guidelines intended to facilitate financing of geothermal projects that incorporate direct use, as long as they are developed alongside electricity generation.

Another alternative is to develop decentralised small-size modular power plants together with direct use facilities for mini-grids, or isolated grids for communities or resource parks. The combined approach for integrated power and direct use may be more economically feasible and so could receive funding from DFIs and even commercial banks.

Prefeasibility studies in Kibiro and Panyimur in Uganda indicate that combined power and direct use project development is economically viable. The proposed project by the community-based AGAP in the Afar region of Ethiopia entails the development of 5 MWe power plants serving the needs of local communities for both electricity and direct uses, including water production. In addition to supplying electricity, such projects are meant to supply thermal energy and water to support the local agro-industrial development, which is based on livestock keeping.

When issues of the water-energy-food nexus are promoted as part of a geothermal project, available incentives may be easier to access. In addition, the decentralised developments in such areas where steam is available at the surface require shallower and cheaper wells to be drilled, thereby lowering the whole project budget.

Direct use could play a catalytic role in diversifying the economies of and stimulating industrialisation in local centres for the countries in the region.

A third alternative, which was used for centuries everywhere in the dry Afar triangle (Djibouti, Eritrea and Ethiopia) and was also applied in Eburru, Kenya, is the development of direct use applications without electricity generation.

In Eburru, steam from a shallow borehole is used to dry pyrethrum and cereals. In addition, the residents condense the steam used in the crop dryer and from steam traps mounted on the ground to provide water for domestic use to compensate for a lack of potable water in the area. The resource has also been assessed to provide energy for honey processing, chick hatching and brooding, heating a greenhouse for a tree nursery, and aquaculture (Kinyanjui and Mburu, 2012).

Other examples in Africa are found in Algeria and Tunisia for greenhouse heating (Lund and Boyd, 2015). These uses are in addition to the numerous *hammams* – traditional hot water and steam baths — which are popular and widespread in North Africa from Morocco to Egypt. These types of projects may be developed around hot springs or by exploiting aquifers at shallow depths, which involve lower drilling costs.

Photograph 10: Eburru geothermal crop dryer

Photo credit: Japheth Towett

Participation of development partners in direct use development

Development partners can play a crucial role in mainstreaming geothermal direct use applications in the region. Through technical assistance programmes, some development partners (*e.g.*, ARGeo-UN Environment, DFID, JICA, USAID and ICEIDA) have supported efforts to develop geothermal direct use in the region. The development partners with activities in East Africa indicated that they can support direct use developments by offering technical assistance, capacity building, and financial support.

The technical assistance could also be utilised to help in the identification of high-value applications since the development of direct use projects is expensive and capital intensive.

The Menengai direct use demonstration project is a successful case study of a direct use project which was implemented in the region due to the collaboration between GDC and a development partner, USAID.

On this occasion, USAID provided technical assistance during the design and implementation of a heated greenhouse, aquaculture unit, a milk pasteuriser, and a laundry unit in the demonstration project.

It also provided support for the development of prefeasibility studies for selected direct use applications as well as on-the-job training/mentoring for GDC staff. ICEIDA, on the other hand, financed the procurement of a grain dryer for GDC, which is also installed in the Menengai demonstration site. JICA has supported GDC with capacity building on direct use while USAID is considering support for the development of geothermal industrial parks in the region. In Uganda, the EAGER project supported the development of prefeasibility studies for selected direct use applications.

The Climate Technology Centre and Network advertised in September 2019 for consultancy services to carry out feasibility studies for direct use applications in Djibouti, Ethiopia, Kenya, Rwanda, Tanzania and Uganda (see Table 5). The GRO Geothermal Training Programme in Iceland has also supported the region in capacity building for direct use.

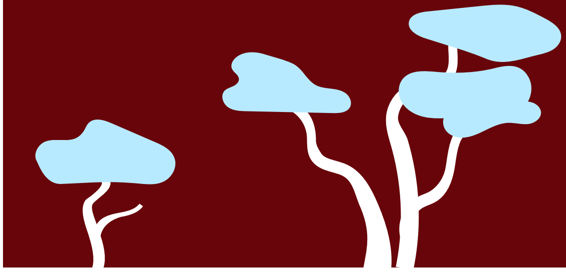
To define effective strategies for the deployment of geothermal direct use projects, it is crucial to involve all relevant players. These include geothermal developers, users of geothermal heat, and ministries and local authorities or county/regional governments. This inclusive process would be beneficial in addressing local challenges that hinder development of direct use.

Some of the challenges include: non-application of the “subsidiarity principle”, which stipulates that all that can be done locally should be handled at that level; an absence of sufficient devolution policies; a weakly developed cooperatives culture; and the absence of a dedicated coordinator.

The New Zealand Geoheat Strategy proposes an implementation structure consisting of a governance group made up of representatives from different players, an action group made up of interested persons to drive the strategy and a dedicated strategy co-ordinator responsible for delivering the outcomes of the strategy (New Zealand Geothermal Association, 2017).

In Kenya, GDC and Nakuru county government entered into a collaboration that would facilitate the supply of affordable geothermal energy to the local farmers and investors; for food production and processing. As of August 2020, a joint committee was expected to be established between the two institutions to implement the collaboration (Kenya News Agency, 2020).

7.



7. HARNESSING DIFFERENT RESOURCE TYPES AND SELECTING EXPLORATION METHODS

Exploring and proving the existence of a geothermal resource is a crucial phase in any geothermal project. The selection of appropriate methods for exploration is therefore designed to maximise the chances of resource discovery in this risky, capital-intensive drilling phase. As such, the exploration phase requires a multi-disciplinary approach involving geological, geophysical and geochemical techniques.

A successful strategy has been to rely on the geological setting to characterise the geothermal resource, which is then evaluated by geophysical and geochemical techniques. The choice of the methods to be used and models to be developed is crucial and should be defined by the geological setting of the prospect to be evaluated. Given this background, this chapter will present the status of knowledge about the most appropriate exploration methods for volcano-hosted systems, fault-controlled systems and shallow resources that are suitable for direct use applications in the region.

7.1 Geothermal resources across the region

As highlighted in the previous chapters, the EARS consists of the eastern branch and the western branch. The eastern branch extends from the main Ethiopian Rift (Djibouti, Ethiopia and Eritrea) through Kenya into northern Tanzania, while the western branch extends from northern Uganda through Rwanda, DRC, Burundi, southern Tanzania, Malawi, Zambia and Mozambique. The tectonic setting and development of the two rift branches have resulted in the occurrence of distinct geothermal resource types which also require different methods for their evaluation (Omenda *et al*., 2016a).

The dominant geothermal systems in the eastern branch are volcano-hosted, high-temperature, and two-phase systems, while the dominant resource type in the western branch is fracture-controlled, low- to medium-temperature, and water dominated. Examples of the volcano-hosted resource type in East Africa include Olkaria, Eburru, Paka and Menengai in Kenya; Aluto-Langano in Ethiopia; and Asal and Fialé Caldera in Djibouti, all of which have been proved by drilling. There are many other potential sites under exploration, and all are associated with central volcanos with or without calderas. However, none of the fracture-controlled systems has been confirmed through drilling.

The differences between the two branches of the rift that control the occurrence and characteristics of the geothermal systems is attributed to the nature of magmatism that occurs therein. In the eastern branch, the volcanoes developed silicic magmas that were able to pond at shallow crustal levels (<6 km), thus contributing to high heat flows under the volcanoes. In the case of the western branch, magmatism is deep source, mafic, and with resultant low viscosity, the magma shoots straight to the surface with no significant accumulation within crustal levels. This explains the lack of or rare occurrences of volcano-hosted systems in the western branch. However, the general high heat flow associated with asthenospheric upwelling would create convective cells along the fractures, which could form viable geothermal reservoirs. Such geothermal systems would also occur in the eastern branch of EARS away from volcanic centres.

Exploration best practices for geothermal resource described here are based on guidelines for collecting, analysing and presenting geothermal data prepared by the International Geothermal Association (IGA and IFC, 2014). Additional discussion relevant to East Africa is presented by Omenda *et al.* (2016b).

The exploration techniques – namely geology and structural mapping, resistivity (MT/TEM), micro earthquake (MEQ), gravity, geochemistry, and heat flow measurements – use the same equipment but are applied differently in the region depending on the resource type (Table 7).

Table 7: Exploration techniques in EARS countries

Method	Eastern branch	Western branch	Shallow resources
Characteristics	Volcano hosted, magma heat sources, distributed heat, deep anomalies	Fracture/fault-controlled, deep circulation, localised anomalies	Commonly low- to medium-temperature resources controlled by fault systems
Geological mapping	Lithologic and structural mapping and fault kinematics	Detailed structural and litho-stratigraphic mapping	Detailed structural and litho-stratigraphic mapping
Geophysics	Gravity, seismics, MT, TEM, heat flow, occasional TGH	Gravity, seismics, TEM, (optional MT), heat flow, TGH	Gravity, seismic, TEM, heat flow and TGH
Geochemistry	Fluid (hot spring), gas (fumaroles), soil gas (radon and CO2)	Fluid (hot spring), soil gas (radon and CO2)	Soil gas (CO2 and radon surveys); fluid sampling and analysis

Source : Omenda *et al.* (2016b)

7.2 Volcano-hosted geothermal systems

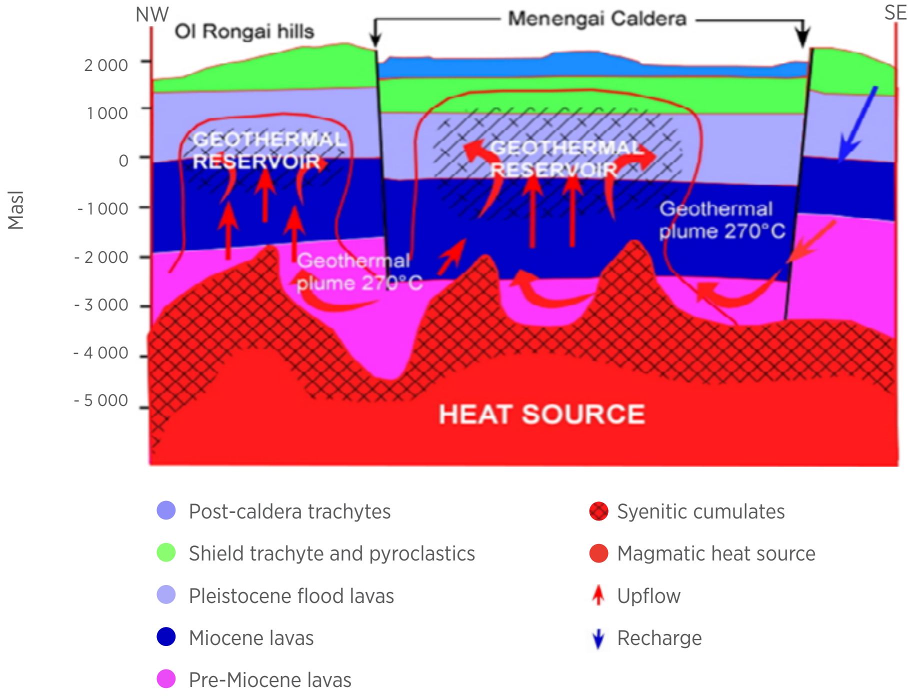
Volcanic geothermal systems refer to geothermal areas where heat transfer is due to a convective reservoir driven by hot rocks or magma under the volcano with an up flow zone under the mountain and outflows to the sides. In the eastern branch, which is dominated by volcano-hosted geothermal resources, the commonly used exploration methods involve the determination and occurrence of distributed heat sources associated with magma chambers under the central volcanoes (Box 14) (Figure 48). A convective cell is driven by a centralised magma heat source with outflows away from the volcanic edifice to form hot springs. The model gives rise to high-temperature resource types (>200°C) dominantly of NaCl and in some fields $NaHCO_3$ (sodium bicarbonate).

Exploration techniques that have been found to be useful in exploring volcano-hosted geothermal systems include geology and fault kinematics studies. Useful geological investigations include determination of the volcanic and petrogenetic evolutionary history.

Most of the prospects associated with East Africa's volcanoes have generally low permeability and targeting structures during exploration results in higher power output. Therefore, it is important to understand the fault patterns and kinematics, as reactivated fault zones with oblique extension tend to be more permeable than straight faults as has been observed at the Olkaria geothermal field in Kenya.

Among the geophysical techniques, resistivity methods are the most favoured as they provide a clearer picture. MT and TEM are commonly used to image both deep and shallow geothermal systems. TEM is often used to image shallow resistivity structures and to correct for the static shift in the MT data to allow for more robust modelling. The resistivity structure of a geothermal system is usually defined by resistive near-surface rocks underlain by a clay-rich zone which is highly conductive. This is the zone where the uprising hot geothermal fluids interact with cooler fluids, thus depositing alteration minerals that include smectitic clays and hematite. The reservoir zone

Figure 48: Model of a high-temperature volcano-hosted geothermal system: The case of Menengai



Source: Omenda and Simiyu (2015)

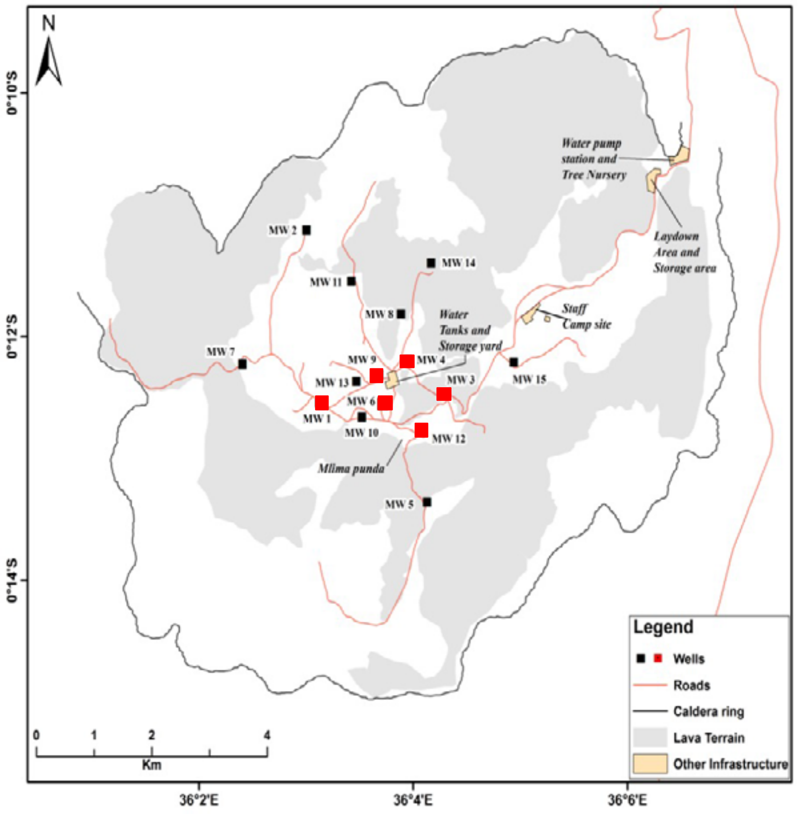
has been determined to have relatively higher resistivity due to higher temperatures and resistive secondary minerals. This picture has clearly been used to explore and site wells at Olkaria and Menengai geothermal fields in Kenya (Box 14).

However, it has been determined that the typical resistivity structure is not conclusive as the resistivity distribution can be caused by other processes other than geothermal, as demonstrated in the case of the Karisimbi area in Rwanda.

Box 14: Exploration methods and lessons learned: The case of Menengai geothermal field, Kenya

Menengai geothermal field is a caldera hosted geothermal system in the central Kenya rift. Menengai is a large trachyte shield volcano. The present elliptical (12 km x 7 km) caldera collapse occurred from about 29 000 years Before Present (BP) followed by resurgent activity on the caldera floor from about 1400 years BP (Figure 49). This latest phase of activity could be responsible for the geothermal system at Menengai because studies indicated anomalies centred within the caldera area of the volcano. Exploration drilling undertaken by GDC beginning in 2011 encountered a two-phase high-temperature geothermal system with a measured downhole temperature of more than 400°C – the highest in Kenya. Some of the wells drilled in Menengai encountered magma at about a 2.3 km depth. The reservoir is hosted within thick trachyte flows. Fracture permeability is most important, and this has produced mixed results with some wells being hot but tight while large producer wells (>30 MWe) have also been drilled in the field. Additionally, the field has high CO_2 content.

Figure 49: Menengai geothermal field



Source: Malimo (2013)

Lessons learned:

- Caldera volcanoes can provide viable geothermal systems with very high temperatures, and the possibility of high non-condensable gases such as CO_2 are expected due to the shallow degassing magma bodies.
- Magma bodies (sills and dykes) associated with resurgent activities are expected at shallow depths under the caldera.
- Understanding the distribution of secondary (fracture) permeability is important since general permeability may be very low – attributed to magma sealing.

Other geophysical methods that have been determined to be useful for geothermal exploration and well siting in the East African Rift countries are gravity and passive seismic/micro earthquake (MEQ). Gravity helps to image the presence of an active or fossil magma chamber that may still have adequate heat to drive a geothermal system.

On the other hand, MEQ has been found to be very useful in supplementing resistivity methods by determining the existence or not of a geothermal system. An active geothermal system would always have microseismic activities associated with either fluid flow along structures, hydrothermal fluid pressure changes or turbulence in the underlying magma chamber, if an active one exists.

Further, MEQ can be used to define the depth to the top of a magma chamber by marking the upper zone of seismic attenuation. Where there exists uncertainty about a geothermal system, it is recommended that MEQ studies are undertaken for about four months or more.

Fluid and gas geochemistry is always a standard procedure for volcano-hosted systems in the EARS. The investigations usually involve shallow soil gas surveys for radon and carbon dioxide, as well as hot spring and fumarole sampling.

High values for the gases have been used to define leakage areas and to suggest the presence of a degassing magma chamber. However, caution is required since there are areas within the rift with elevated carbon dioxide gas originating from the mantle as opposed to shallow degassing magma bodies.

Fumarole and hot spring chemistry are usually used to characterise the geothermal reservoir in terms of chemistry and resource temperature. However, recent findings are that the chemistry of geothermal fluids in EARS are markedly different from those in other tectonic settings such as the Pacific Rim, among others; therefore, the fluids are classified differently as they are inherently chloride poor due to the nature of volcanism (Omenda *et al.*, 2016a).

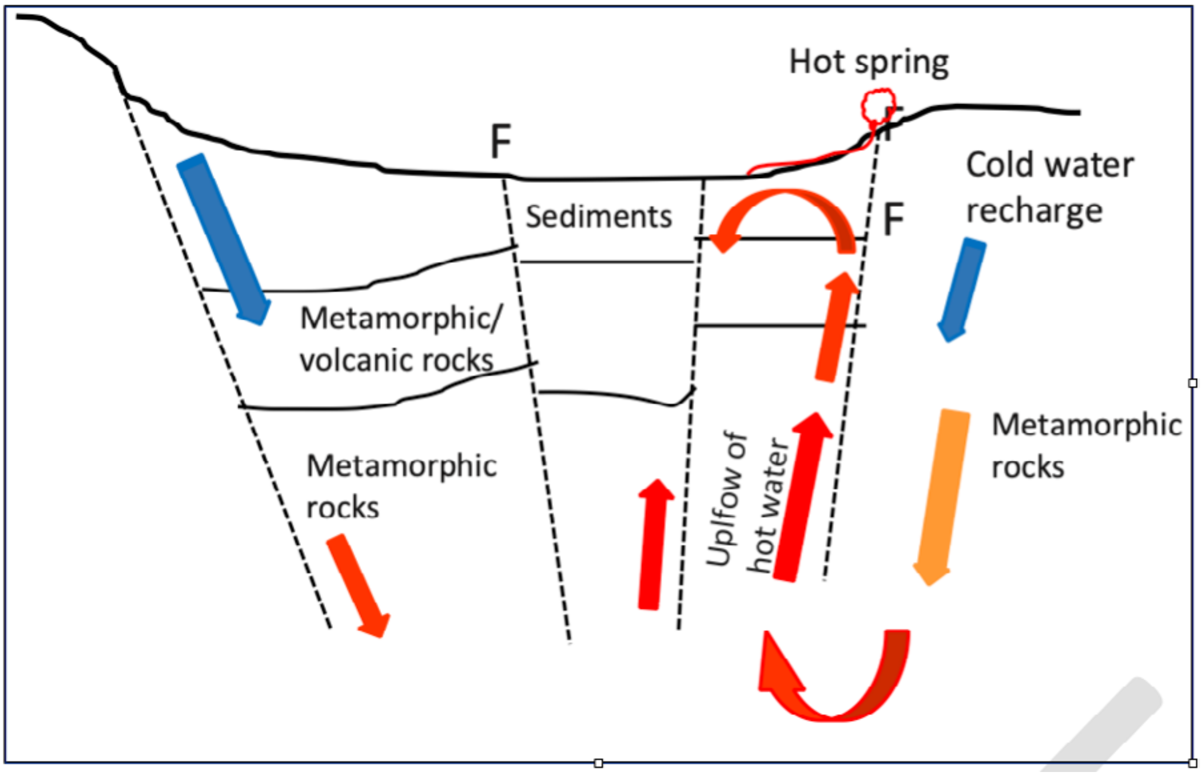
Finally, some complex geothermal systems can be evaluated using thermal gradient wells drilled to 200-400 m depths.

7.3 Fault-hosted geothermal systems

Fault-hosted, or controlled geothermal systems are also referred to as "conduction-dominated geothermal play types" by Moeck and Beardsmore (2014) and are commonly characterised by limited convection of fluids within the reservoir. The fault-hosted geothermal systems usually occur in areas that have undergone neither significant recent tectonism nor volcanism. In these systems, heat is mainly transferred through conduction. In EARS, these areas occur within the western branch including in Burundi, the DRC, Malawi, Mozambique, Rwanda, Tanzania, Uganda and Zambia. The economic viability of the fault-hosted systems is a function of the geothermal gradient, which in the case of EARS is higher than the global average[8] along the entire rift valley. Fault-hosted geothermal systems have no centralised heat sources, and fluids circulate in the deep subsurface, mining heat along fault zones and within the base of the sedimentary basins (Figure 50). The resource temperature is commonly less than 180°C. The exploration techniques applied in the western branch include geology, various geophysical methods, geochemistry, passive seismics and heat flow measurement using thermal gradient holes (Omenda *et al.*, 2016b).

These techniques are also applicable to suspected fracture-controlled systems in the eastern branch. In EARS, the fault-hosted systems fall largely into two types: i) basement rock such as granite, whose permeability is due to faulting or fracturing rather than porosity, *e.g.* in Tanzania and western Uganda; and ii) sedimentary basins associated with old faulted and subsided terranes, *e.g.* the Rufiji basin of Tanzania and some prospects in Zambia.

Figure 50: Sketch of a typical fault-hosted geothermal system in a rift setting



Source: Omenda *et al.* (2016a)

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[8] The geothermal gradient is the increase in temperature of the subsurface with depth. The normal geothermal gradient in the first 3 km to 5 km of continental crust is typically about 25°C/km but is much higher in anomalous areas.

This, therefore, implies a different strategy for the exploration of the resources in the fault-hosted systems. Geological mapping is undertaken using standard techniques; however, structural mapping and interpretation of fault kinematics are paramount (Faulds and Hinz, 2015).

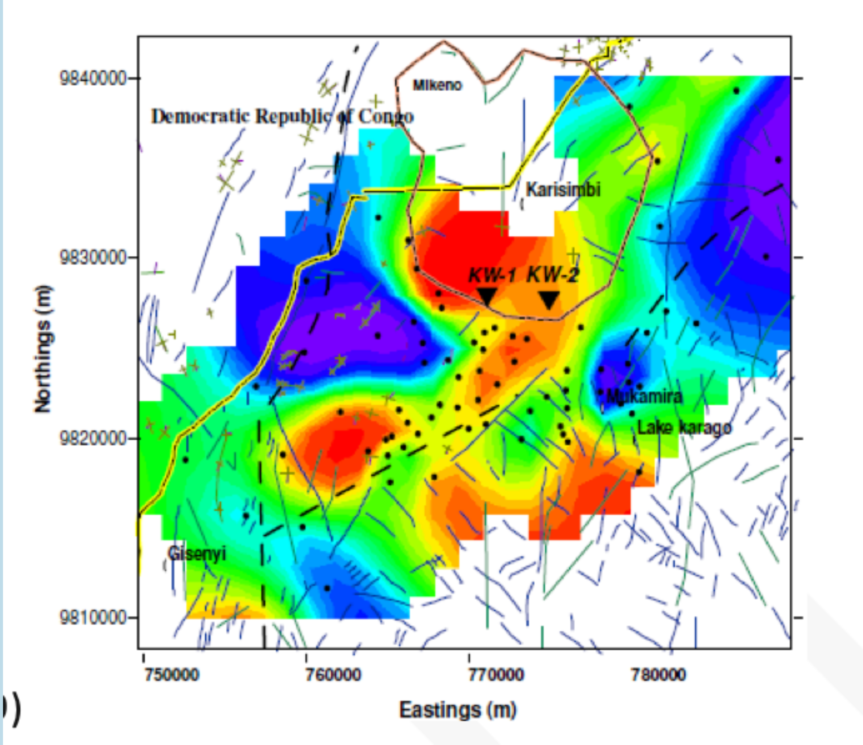
The geophysical techniques to be employed are those focused on locating the reservoir along the fault planes. The methods include MT/TEM, gravity and microseismics. MT/TEM is used to image shallow resistivity structures to locate geothermal reservoirs, typically occurring at less than 3 km of depth (Box 15). MEQ and gravity techniques are useful in locating the fault/fracture zones, which could host geothermal reservoirs. Heat flow measurements are potentially very important as a tool for evaluating fault-hosted geothermal systems. The heat flow is determined through TGH drilled from 100 m to a maximum of 400 m of depth. The geochemical methods applied are usually restricted to sampling hot springs to help with estimating the reservoir temperatures and characterising the reservoir fluid.

Box 15: Exploration methods and lessons learned: The Case of Karisimbi geothermal prospect, Rwanda

Geothermal exploration in Rwanda was undertaken between 1983 and 2015 with the period of 2010-2015 concentrated in the Karisimbi geothermal area in western Rwanda (Figure 51) (Jolie *et al*., 2009; Shalev *et al*., 2012). Whereas geothermal manifestations in the area occur at Gisenyi, the studies resolved to focus on the Karisimbi area based on results of geology, geophysics and the geochemistry of fluids discharging near Lake Karago. The prospect at Karisimbi was thought to be a volcano-hosted high-temperature geothermal system.

The rocks in the area are dominated by basalt and evolved intermediate products with trachytic units and pyroclastic equivalent occurring on the upper slopes of the volcano. These occurrences were thought to suggest the presence of a shallow magma body under the volcano. However, the bulk of the more mafic products suggest depths greater than 10 km (Shalev *et al.*, 2012). Geochemistry data relied on the carbonate-rich, warm and cold discharges on the western edges of Lake Karago, which were thought to originate from Karisimbi Volcano. MT/TEM data from Karisimbi indicate a conductor in the southern slopes of the volcano (see figure below). Microseismic studies undertaken over a four-month period showed intense seismic activity in the area to the east of Nyiragongo Volcano in the DRC, but only one or two events over the same period in the Karisimbi area. Exploration drilling of two wells, KW-01 and KW-02, failed as the wells encountered temperatures of only about 120°C at more than 2 km of depth.

Figure 51: Karisimbi geothermal area



Source: KenGen (2009)

Lessons learned:

- A combination of geological and geophysical techniques are required to determine the type of geothermal resource in a given field. Petrogenetic modelling is important to understand the depth of magma storage and differentiation.
- Graphitic schist lenses commonly occur within the metamorphic rocks that are abundant in western branch of the EARS and may show electric conductors that may be misinterpreted for geothermal systems.
- Microseismic studies are useful in discriminating among geothermal systems because active systems always show significant seismic activity within the geothermal prospect.
- The results of drilling showed normal geothermal gradient in Karisimbi, indicating the absence of a shallow and centralised heat source. Potassic magmatism tends to pond at deep levels.

Fault-hosted geothermal systems have traditionally been considered riskier than volcano-hosted systems because of their smaller reservoirs and the high likelihood of being low-medium enthalpy. As reported by stakeholders from the western branch of the rift valley in their response to a survey undertaken during the development of this study, this risk perception resulted in a lack of support for the development of such systems. However, development partners indicated that they would be interested in offering support for the development of these systems for power generation and direct use.

7.4 Exploration of shallow resources for direct use

Shallow geothermal systems are those that have reservoirs at depths not greater than about 500 m. Most occurrences of the geothermal resources in eastern Africa are of low to medium temperatures, and yet they are mostly not well defined. Previously these resources were explored using methods that are best suited for volcano-hosted high-temperature systems. These low- to medium-temperature resources are usually shallow and commonly associated with buried faults and fractures (Figure 47).

Some of these systems occur as a result of steam leakage zones forming above high-temperature systems (Onyango and Varet, 2018; Mariita, Onyango and Varet, 2016). The appropriate exploration technologies are largely similar to those used for investigating fracture-controlled systems. Common geological investigation methods include lithological mapping, identification of thermal leakage zones, and faults and fracture systems, which often form outflow and storage channels.

The geological anomalies should then be confirmed by gas and fluid chemical analysis to provide an estimate of the resource temperature and main fluid leakage channels through soil-gas analyses. The geophysical techniques that are appropriate for the identification of shallow resources include TEM, gravity, microseismicity, self-potential (SP) and electric tomography.

The geophysical techniques would be used to identify shallow buried structures and shallow anomalies that may be associated with geothermal reservoirs. Shallow resources are mainly used in Europe and countries with cold climates for space heating of homes and melting of ice on walkways.

In the East African Rift region, these resources could be used to provide potable water (from shallow steam sources), bathing for tourism, aquaculture heating, food drying and many more applications requiring heat (see Chapter 2, Section 4 and Chapter 6).

8.

8. CAPACITY AND WORKFORCE DEVELOPMENT

As highlighted in Chapter 3, the survey carried out during the preparation of this report revealed that most stakeholders involved in geothermal resource development consider low awareness and lack of a sufficiently large specialised workforce to be major hindrances to geothermal development in the East African Rift region. Only Kenya has a well-developed geothermal workforce in the region.

The expertise required for geothermal development includes the following: geothermal geology, borehole geology, hydrogeology, geochemistry, geophysics, reservoir engineering, drilling technology, and power plant engineering for electricity and direct use applications. The required knowledge may be obtained through formal training in universities and colleges, but practical skills also need to be developed within local workplaces.

Other capacity gaps identified by the stakeholders include inadequately skilled project managers and environmental and social scientists. Additional skills required include methodologies for well citing to improve the success rate of drilling and assessing the viability of direct use applications.

Since local universities have traditionally not offered courses to address these skill gaps, the geothermal developers, as well as development partners, invested resources in providing the necessary training. As an example, the United Nations University Geothermal Training Programme (UNU-GTP) – now renamed Centre for Capacity Development, Sustainability and Societal Change in IcelandGeothermal Training Programme (GRO-GTP) and sponsored by UNESCO – has over the years played a significant role in developing local expertise in geothermal science and engineering.

The three-week course on geothermal exploration held annually in Kenya in collaboration with GDC and KenGen, as well as the specialised six-month course held annually in Iceland, have contributed to improvements in the skill gap.

Other learning institutions, such as the Geothermal Institute in the University of Auckland, Kyushu University and Oregon Institute of Technology's GeoHeat Centre, among others, have also contributed to the development of geothermal expertise in the region.

The New ZealandAfrica Geothermal Facility (NZ-AGF), a partnership between the New Zealand Ministry of Foreign Affairs and Trade and the AUC, is offering capacity-building programmes to countries in the East African Rift region on various geothermal development aspects. In collaboration with the Africa Geothermal Centre of Excellence (AGCE), the University of Auckland and the government of Kenya, NZ-AGF offered training on Leapfrog visualisation programme to students from Djibouti, Ethiopia, Kenya, Uganda and Tanzania; with the aim of building skills of geoscientists and reservoir modellers within the region. In addition, the facility is planning to implement a drilling-related training drawing on people from a range of East African countries, including private sector participants with geothermal projects in the pipeline.

More recently, public geothermal developers in the region who have acquired substantial expertise, such as in Kenya, have started to assist the other EARS countries to build on their geothermal expertise. In 2018 GDC trained young geothermal professionals from ODDEG in courses such as fluid chemistry, reservoir engineering, drilling simulation, cementing of geothermal wells, rig maintenance, geothermal procurements, as well as environmental and social management of geothermal projects. Young geothermal professionals from other countries in the region with geothermal potential (Ethiopia, Rwanda and Tanzania) have previously been trained by GDC (GDC, 2018). In addition, KenGen runs the Geothermal Training Centre in Olkaria, which offers training in geosciences, basic computer skills, environmental sciences, geothermal technology, safety, management skills and drilling technology to its staff as well as internships for local and international students (KenGen, 2019).

Photograph 11: AGCE-sponsored geothermal training session facilitated by GDC and KenGen

Photo credit: GDC

Stakeholders interviewed during this study indicated that lack of awareness among policy makers, industries and local communities is a significant factor hampering geothermal development in the region, especially for direct use.

Therefore, tailor-made capacity building programmes may be designed taking into consideration specific target groups of stakeholders. They should address knowledge gaps in areas such as geothermal policy, legal and regulatory frameworks for both electricity and direct use, geothermal financing and available financing mechanisms, as well as direct use development and associated socio-economic benefits.

IPPs who are active in the region identified a lack of local capacity to handle complex geothermal transactions and recommended that local authorities be trained on geothermal procurement as well as other geothermal transactional aspects. These include, among others, designing and negotiating PPAs as well as selection/procurement of competent geothermal developers.

Capacity building may also be focused on supporting decision making and not only imparting technical or commercial knowledge. In particular, coaching and mentoring was successfully implemented through a technical assistance programme run by EAGER to strengthen institutional capacities in the region. The major advantage of this approach is that the staff are trained on the job and as a result, they continue to implement projects as they learn (Heath *et al.*, 2018).

Furthermore, experts participating in a Geothermal Financing and Risk Mitigation workshop in Nairobi in 2018 indicated that capacity building should be tailored to match the geothermal development model adopted by each country, and that the bigger the role a government plays in geothermal development, the bigger the financial and human capacity requirements (Sussman, 2018).

An analysis carried out by UNEP in 13 countries of the East African Rift region proposed increasing the number of geothermal personnel available in 2015 by 70% for geoscientists, 90% for reservoir and drilling engineers, and 84% for power plant engineers in order to achieve 10 GWe of geothermal installed capacity by 2030 (UNEP, 2015).

Appropriate skills development for the geothermal industry should therefore be undertaken as a matter of urgency so that countries' targets are achieved. This realisation supports the establishment of the AGCE, which aims to impart practical skills to those working in the geothermal industry in Africa so as to build a critical mass of geothermal professionals (Box 16). AGCE may help with certification for some special skills that require international certification before technicians can handle some activities, *e.g.* geothermal drilling.

AGCE could further collaborate with geothermal developers, governments, local colleges, private training centres, development partners and universities to develop curricula and methodology for training to ensure that the geothermal capacity needs of the region are addressed.

Box 16: Africa Geothermal Centre of Excellence

Geothermal development is a highly skilled activity, and significant scientific research is needed before development and utilisation of the resource can be actualised. High levels of uncertainty, mainly related to the characteristics of geothermal resources, call for substantial competence in countries that wish to utilise geothermal resources. Several countries with significant geothermal resources have provided specialised geothermal training for decades to local as well as international trainees. Most notable in this context include the Centre for Capacity Development, Sustainability and Societal Change in Iceland Geothermal Training Programme (GRO-GTP) and geothermal training schools in New Zealand, Italy, Japan and the United States.

According to analysis by UNEP, the potential and ambition of East African countries to develop geothermal energy projects calls for the training and recruitment of more than 12 000 skilled people in the scientific and engineering disciplines of geothermal technology (UNEP, 2015).

The skills gap study undertaken by UNEP (2015) clearly indicated that the most efficient way of achieving the required human capacity is through a regional training facility. It was decided that such a centre should be based in Kenya due to the country's leadership in geothermal utilisation, which includes a significant cadre of geothermal specialists and geothermal facilities in full operation. Through the support of development partners, a feasibility study was undertaken in 2015 and its results presented at a validation workshop for stakeholders in Nairobi in August 2015. The outcome of the feasibility study was a recommendation to set up the Africa Geothermal Centre of Excellence, or AGCE. The AGCE is operational and is currently hosted at the UNEP for technical and management support on an interim basis. Kenya's Ministry of Energy represents the host country in providing support to the facility.

The AGCE, in collaboration with GDC and KenGen, conducted its inaugural training on geothermal technology in Kenya in 2018, where 22 students from 11 African countries were trained (GDC, 2018).

As highlighted in the previous chapters, the increased utilisation of shallow geothermal resources may lead to an accelerated uptake of direct use. This will require the development of techniques for exploration of shallow geothermal resources, as discussed in Chapter 7. Discovery of shallow geothermal resources could help to fast-track the development of direct use as it would be cheaper to drill and generate steam/hot water to the surface.

The available courses on geothermal drilling technology primarily focus on deep drilling of high- and medium-temperature geothermal resources for a depth range of 1 km to 3.5 km and a final well size diameter of 8.5 inches, however. These wells are too expensive for stand-alone direct use projects. It is recommended that capacity should be developed for drilling of shallow, large diameter wells using smaller rigs. The depth of such wells is estimated at around 500 m.

Besides, geothermal resources in the countries of the EARS are usually found in remote and semi-arid areas where local communities engage in various economic activities such as pastoralism, fishing, beekeeping and crop cultivation and have limited access to water. The use of geothermal heat in the value chains of these economic activities can contribute to better living standards for the local communities and address the water-energy-food nexus issue.

As highlighted in Chapter 6, training of experts on how to screen and identify value chains that can benefit from direct use of geothermal is necessary so that feasible projects can be recommended for development. The training may cover topics such as financial and economic analysis, energy demand and supply estimations, project costing, and project management. Others include engineering design, wastewater/brine treatment and disposal, and workplace safety.

The inclusion of local communities in geothermal project development is another critical issue to be considered given that most of the community members are pastoralists and live in arid areas with scarce water and energy sources.

These areas also have fragile ecosystems which should to be protected. Hence, training aiming to enhance the capacity of key actors on environmental issues as well as community and stakeholder management may also be paramount for the development of successful geothermal projects that could ultimately also benefit local communities.

With support from USAID and Power Africa's East Africa Geothermal Partnership, KenGen has emerged as a regional leader in this field by developing a comprehensive, values-based strategy for community engagement for large infrastructure projects. The strategy is designed to identify areas of mutual benefit for project developers and local communities (Smith *et al*., 2018).

9.

9. CHALLENGES AND KEY RECOMMENDATIONS

9.1 Main barriers to geothermal development

This report shows that, despite the East African Rift region's large geothermal potential, only Kenya and Ethiopia had installed geothermal power plants, as of May 2020. Other countries are still at different stages of surface exploration and/or drilling activities.

The analysis in this report has identified and discussed various challenges that have hindered the development of geothermal projects in the region for decades, including the following:

» Limited awareness about the potential and benefits of direct use applications among policy makers, entrepreneurs and communities. As a consequence, risk mitigation instruments and other incentives do not cover direct use projects.

» Raising finance for the exploration phase – before the resource is proven – leads to a large initial equity requirement with high capital costs, which may undermine the viability of a project. On the other hand, there are limited public financial resources to carry out geothermal development or to de-risk a geothermal project and attract private investors.

» A lack of adequate policies and regulatory regimes in most countries has hindered the flow of geothermal investments into the region.

» With the exception of Kenya, a shortage of a skilled local geothermal workforce and the technical capacity to undertake all stages of geothermal development.

» Limited understanding of the geological setting of the western branch of the EARS, until recently, as well as a lack of appropriate exploration and development techniques suited to the Western rift, resulting in a higher perceived resource risk.

» The unfavourable chemistry of geothermal fluids such as in the highly saline Asal geothermal resource in Djibouti.

As a result of the challenges identified above, several projects in the region are stuck at the exploration stage.

9.2 Key lessons learned and recommendations

Building on the analysis of the experiences from Comoros, Djibouti, Ethiopia, Kenya, Tanzania, Uganda and Zambia, it is possible to draw some lessons and recommendations to improve the enabling frameworks, and thereby accelerate the deployment of geothermal energy for electricity generation and direct use in the region.

Policies and regulatory framework

- Transparent and predictable licensing and administrative procedures are essential prerequisites for attracting geothermal developers and investors.
- Well-structured PPAs negotiated by all parties that take into consideration project risks and a reasonable duration for negotiations have been demonstrated to support private sector participation in geothermal development. Dedicated training and capacity building for public institutions, together with the development of standardised documentation, may facilitate negotiations for legal agreements.
- The establishment of strategic geothermal institutions and departments within energy ministries has also been shown to accelerate progress in geothermal development.
- Recent developments with the Corbetti and Tulu Moye projects in Ethiopia suggest that, with the current risk mitigation mechanisms and when stable PPAs and policies are put in place, early involvement of private developers in greenfield geothermal projects may be a successful option in the region.
- Clear fiscal or financial incentives should be developed for all geothermal projects (power and direct use). These could include attractive land rental fees, duty waivers and tax holidays. In addition, frameworks to establish energy (heat/steam) tariffs for direct use could be developed.
- Distinct and clear policies and regulations for direct use projects should be enacted together with those that cover CHP projects. Dedicated, and as much as possible streamlined, authorisation procedures should be developed for small-scale power projects and stand-alone direct use projects.

Financing of geothermal projects

- Public finance has contributed to geothermal development in the region and will continue to be considered for financing the early stages of geothermal projects. This could open up high-potential geothermal fields for further development. However, it is crucial to involve the private sector as early as possible in the project.
- Available and forthcoming financing schemes could be used for raising equity to finance geothermal projects, particularly in early stage development, as in the case of InfraCo Africa in the Corbetti project in Ethiopia (see Box 7).
- Risk mitigation schemes and financial support may be considered for both power and direct use projects. Public-private well-productivity insurance schemes could complement existing support mechanisms and further encourage private sector involvement.
- Technical assistance and project facilitation tools are already available in the region. However, further support may be required to help some project developers access much-needed affordable finance to unlock the many projects stuck at the exploration stage.
- The case in Kenya and the emerging developments in Ethiopia suggest that adopting a strategy of phased development allows for information gathering about the geothermal reservoir. Such a strategy minimises the associated geothermal resource risk, which in turn can attract financing for further expansion of the project.

- For integrated power and direct use projects, factoring in possible revenues from direct use projects as early as possible in the project planning phase could be important.
- As a strategy, wellhead power plants can be adopted to reduce the lead time for geothermal projects and generate some revenue during the construction phase.
- Acquisition of capital-intensive drilling rigs may not be recommended during the early phase of geothermal development in a country but, based on the size of the geothermal market and the number of projects in the pipeline, could be considered after successful exploration to help lower the cost of drilling.

Direct use

- Awareness creation of the potential for direct use and its associated benefits, such as possible lower tariffs to industries, should be targeted towards decision makers, communities and industries. Appropriate tools to assess the viability of direct use projects should be developed or adapted from other sectors.
- Development of direct use involves a diverse group of stakeholders. Centralised coordination of these stakeholders' activities could result in faster development.
- Accelerated development of direct use in the region may benefit from master plans for geothermal heat utilisation aligned to industrial and rural development strategies. The master plan might be for CHP or standalone direct use projects and could be used to inform a review of NDCs with a focus on end-use sectors such as industry and agriculture. Developing a master plan for geothermal heat utilisation could benefit from the involvement and expertise of geothermal industry players, as was the case in the Netherlands and New Zealand.
- Licensing of direct use projects should be streamlined and regulations clearly spelt out. These have not been developed in most countries in the region.
- Demonstrating the financial viability of direct use projects and the development of suitable business models should be supported. This should also involve the development of heat tariffs, which could be used as a basis for negotiating heat purchase agreements.
- The resource park model developed in Iceland has proven successful in enhancing the viability of geothermal development by attracting industries and creating new jobs. East African Rift countries have the potential to replicate this model, including through the Geothermal Village concept, in which geothermal resources are used as a catalyst for the development and socio-economic transformation of isolated communities.

Exploration methods for high-temperature and low- to medium-temperature resources

- In the eastern branch of the East African Rift, high-temperature resources are associated with a centralised heat source above which a geothermal reservoir is expected. These systems are therefore explored with standard techniques that probe deep reservoirs and map heat sources. These include MT/TEM, seismic, gravity, geological mapping and geochemical techniques.
- For the western branch of the East African Rift, exploration techniques will be those focused on the determination of fault planes and shallow geothermal reservoirs. In this case, the determination of heat sources is not important to the models. Similar techniques are appropriate for low- to medium-temperature resources in the eastern branch, since most of them are also associated with fractures or fault systems.

Capacity and workforce development

- Information and training targeting policy makers and users at all levels may improve knowledge of the holistic utilisation of geothermal resources and benefits that would accrue from them.
- Training addressing local communities close to geothermal resources, including on environmental issues, may contribute to raising awareness, improving social acceptance and opening opportunities for direct use projects.
- Capacity building for public institutions may be focused on supporting decision-making, and not only on imparting technical or commercial knowledge.
- Mentoring focused on supporting decision making for government agencies could be a more efficient and sustainable training model than traditional training and would result in significant hands-on experience.
- Training for direct use could focus on exploration and drilling methods for shallow geothermal resources as well as on developing skills for identification and assessment of the viability of direct use projects. The latter could also entail the development of appropriate tools and methodologies to support the assessment.
- Boosting skills development for geothermal professionals in the region should be further supported. AGCE could support the countries to develop expertise for geothermal development.
- Sharing of geothermal knowledge and skills among the countries in the region, as is being implemented in Kenya by KenGen and GDC through their respective training centres, could contribute to narrowing the technical skill gap in the region. These trainings could be organised in the framework of the AGCE.

In conclusion, it is worth noting that the countries in the EARS region are making commendable efforts to develop their geothermal resources. Some countries, such as Ethiopia and Kenya, have developed licensing procedures for geothermal energy development, while other countries are at various stages of developing conducive regulatory frameworks. The activities being undertaken by the countries to this end include the development of geothermal policies, in Uganda; the establishment of legal and regulatory framework in Comoros and Djibouti; and the development of technical capacities in all the other countries.

Despite these efforts, more requires to be done at a faster to realise the full potential and benefits of the region's geothermal resources. To this end, governments and development partners can collaborate to spur geothermal development in the region. In this context, and given the high up-front cost and the high risk profile of geothermal development, it may be important to expand the number of development partners beyond those who have traditionally been involved in the region over the last decades, in addition to the continued support from currently active development partners.

In particular, some areas requiring support from development partners include the following:

- Development of policy, institutional, legal and regulatory frameworks to attract investment in renewable energy, particularly geothermal energy, focusing on both generation of electricity and deployment of direct use.
- Support for the development of complementary financing and risk mitigation schemes as well as the extension and expansion of existing schemes, in collaboration with governments, to address the financing needs of geothermal projects for power and direct use.
- Enhancing capacities to empower decision makers and technical staff.
- Support the feasibility assessment of direct use applications as well as the development and implementation of geothermal heat roadmaps and dedicated incentives.

REFERENCES

REFERENCES

Abdallah, R. (2018), *Geothermal risk mitigation facility*, African Union Commission, Department of Infrastructure and Energy, Nairobi, https://irena.org/-/media/Files/IRENA/Agency/Events/2018/Jan/Geothermal-financing/S4-p2-GRMF-AUC-IRENA-Presentationpdf?la=en&hash=626AA38E2DA2DFA64135B1007F0B6C596BCD1803.

ABiQ (2019), *Reports: ABiQ*, www.abiq.io/kenya-power-sector-q2-2019/ (accessed 29 September 2019).

AFREC (2018), *Key Africa energy statistics*, Africa Energy Commission.

Afrik21 (2020), *Uganda: Geothermal exploration suspended in Kibiro, Panyimur and Buranga*, www.afrik21.africa/en/uganda-geothermal-exploration-suspended-in-kibiro-panyimur-and-buranga/ (accessed 30 April 2020).

Akker, V.D. (2018), *Geothermal energy powering Kenya's future – Menengai geothermal field development facilitated by public-private partnerships: Case studies*, International Finance Corporation, Washington, DC.

Alexander, K. (2016), *Technical review of geothermal potential of Kibiro Springs, Uganda,* ARGeo-C6, ARGeo-UNEP, Addis Ababa.

Alhaji (2020), *Construction of Aluto Langano small geothermal power plant in Ethiopia to commence*, Construction Review Online (accessed 10 March 2020).

Anlil-Wafa, A. *et al.* (2018), *Comoros geothermal project: Exploration drilling infrastructure assessment*, Proceedings of the 7th African Rift Conference, Kigali, Rwanda, ARGeo, Kigali, pp. 12.

ATI (2020), *Energy solutions*, Africa Trade Insurance Agency, www.ati-aca.org/energy-solutions/facilities/regional-liquidity-support-facility/ (accessed 26 February 2020).

AUC (2018), First progress report of the Chairperson of the Commission on the Geothermal Risk Mitigation Facility: 15 May 2018, African Union Commission, https://au.int/sites/default/files/documents/34306-doc-3final_english_cp_report_to_prc_geothermal_risk_mitigation_facility_april_18_pn_-formatted_eng.pdf

Aurecon (2018), *SAPP-EAPP interconnector impact study*, Aurecon.

Bahati, G. and J.F. Natukunda (2018), *Geothermal energy exploration in Uganda, country,* ARGeo, Kigali, pp. 23.

Bahati, G. *et al.* (2005), "Hydrology and reservoir characteristics of three geothermal systems in western Uganda", *Geothermics*, Vol. 34, pp. 568-591.

Beyene, T., D.P. Lettenmaier and P. Kabat (2006), "Hydrologic impacts of climate change on the Nile River basin: Implications of the 2007 IPCC scenarios", *Climatic Change*, Vol. 100, pp. 433461, www.researchgate.net/publication/225758734_Hydrologic_Impacts_of_Climate_Change_on_the_Nile_River_Basin_Implications_of_the_2007_IPCC_Scenarios - read.

Calais, E. (2016), "Le rift est Africain, laboratoire de la rupture continentale" [The rift is African, laboratory of continental rupture], *Geosciences,* Vol. 21, pp. 28-32.

Capital Business (2019) (13 May), *KenGen inches closer to fully redeeming Sh25bn PIBO,* Capital Business, www.capitalfm.co.ke/business/2019/05/kengen-inches-closer-to-fully-redeeming-sh25bn-pibo/.

CAPP (2020), *Members*, Central Africa Power Pool, www.peac-sig.org/en/members.html.

CDK (2017), *Mapping of energy institutions in Ethiopia*, Climate and Development Knowledge Network, London.

Chaheire, M., M. Chamassi and N. Houmadi (2016), *Geothermal development in the Comoros and results of geothermal surface exploration*, ARGeo, Addis Ababa, pp. 9.

CTCN (2019), *New CTCN/UNIDO call for proposals: Applications and technologies in geothermal systems in 6 African countries,* Climate Technology Centre and Network, www.ctc-n.org/news/new-ctcnunido-call-proposals-applications-and-technologies-geothermal-systems-6-african.

DAGO *et al.* (2018), *Master plan geothermal energy in the Netherlands: A broad foundation for sustainable heat supply,* Dutch Association Geothermal Operators.

DiPippo, R. (2016), *Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact,* Elsevier, Waltham.

Dipippo, R. (2012), "Geothermal power plants: Principles, applications, case studies and environmental impact", In *Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact,* Elsevier, Waltham, pp. 587.

EACREEE (2019), *About EACREEE*, East African Centre for Renewable Energy and Energy Efficiency, www.eacreee.org/.

EAGER (2018), *Pre-feasibility for combined power plant and direct use facilities*, East Africa Geothermal Energy Facility.

EAPP (2014), *EAPP regional master plan 2014*, Eastern Africa Power Pool, Addis Ababa.

Energy Central (2020), *Firms offered incentive to create jobs in Naivasha*, Energy Central News, https://energycentral.com/news/firms-offered-incentive-create-jobs-naivasha.

ERB (2017), *Energy sector report 2017 (Zambia)*, Energy Regulation Board, Lusaka, Zambia.

ESMAP (2018), *Opportunities and challenges for scaling up geothermal development in LAC,* Energy Sector Management Assistance Programme, World Bank, Washington, DC.

ESMAP (2016a), *Greenhouse gases from geothermal power production*, Energy Sector Management Assistance Programme, World Bank, Washington, DC.

ESMAP (2016b), *Comparative analysis of approaches to geothermal resource risk mitigation: A global survey*, Energy Sector Management Assistance Programme, World Bank, Washington, DC.

ESMAP (2012), *Geothermal handbook: Planning and financing power generation*, Energy Sector Management Assistance Programme, World Bank, Washington, DC.

EY (2020), *Kenya proposes Tax Laws Amendments Bill*, 2020, www.ey.com/en_gl/tax-alerts/kenya-proposes-tax-laws-amendments-bill-2020.

FAO and GIZ (2019), *Measuring impacts and enabling investments in energy-smart agrifood chains*, Food and Agriculture Organization, Rome and Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH.

Faulds, J.E. and N.H. Hinz (2015), *Favorable tectonic and structural settings of geothermal systems in the Great Basin,* World Geothermal Congress, International Geothermal Association, Melbourne, pp. 6.

Federal Democratic Republic of Ethiopia (2016), Proclamation No. 981/2016: A proclamation to provide for Geothermal Resources Development, Federal Negarit Gazette, Federal Democratic Republic of Ethiopia, Addis Ababa.

Gardo, I.A. and J. Varet (2018), *Dabbahu (Teru Woreda) in Northern Afar: A major Ethiopian Geothermal Site Leased by AGAP*, Proceedings of the 7th African Rift Geothermal Conference, Kigali, Rwanda.

GDC (2018a), *GDC to up geothermal training for African countries* (22 May blogpost), Geothermal Development Company, www.gdc.co.ke/blog/gdc-to-up-geothermal-training-for-african-countries/.

GDC (2018b)*, ODDEG trainees graduate* (3 September blogpost), Geothermal Development Company, www.gdc.co.ke/blog/oddeg-trainees-graduate/

GDC (2017a), *Who we are*, Geothermal Development Company, www.gdc.co.ke/about_us.php.

GDC (2017b), *How GDC works*, Geothermal Development Company, www.gdc.co.ke/how_we_work.php.

GDI (2018), *Facilitating geothermal field development through public-private partnerships in Menengai, Kenya*, Global Delivery Initiative, www.climateinvestmentfunds.org/sites/cif_enc/files/knowledge-documents/kenya_2_pages_revised.pdf.

Geological Survey of Ethiopia (2019), *Geological survey of Ethiopia,* Geological Survey of Ethiopia.

Geotermica Italiana (1988), *Integrated geophysical survey in the Menengai and Suswa-Longonot areas of the Kenya Rift Valley: TCD-CON 7/85-KEN 82/002, final report*, UN-DTCD, New York.

Government of Kenya (2019), The Energy Act, 2019, The Government Printer, Nairobi.

Government of Kenya (2013), Public Private Partnership Act No. 15, 2013, Republic of Kenya, Nairobi.

Government of Kenya (1990), *Geothermal resources regulations*, Government of Kenya, Nairobi.

Government of Kenya (1982), Geothermal Resources Act No. 12 of 1982, Rev. Ed. 2012, Government of Kenya, Nairobi.

Government of Uganda (2016), Formulation of Geothermal Energy Policy, Legal and Regulatory Framework in Uganda: Geothermal Resources Development Draft Bill-2015-022/UGA, CTCN, Kampala.

GRC (2019), *Uganda: Exploration drilling for geothermal energy to start next month* (23 December blogpost), Geothermal Resources Council, https://geothermalresourcescouncil.blogspot.com/2019/12/uganda-geothermal.html.

GRMF (2018), *Project overview and activities,* Geothermal Risk Mitigation Facility, African Union Commission, Addis Ababa.

Hafner M. *et al.* (2019), "Renewables for energy access and sustainable development in east Africa", *SpringerBriefs in Energy*, Springer, Cham.

Heath, J. *et al.* (2018), *Advancing geothermal development in east Africa: Lessons learned during the 20152018 EAGER Programme*, Proceedings of the 7th African Rift Geothermal Conference, 31 October2 November 2018, Kigali, Rwanda.

Hendawi, H. (2020), *Egypt takes dispute over Ethiopia's Nile dam to Security Council,* N World, www.thenational.ae/world/mena/egypt-takes-dispute-over-ethiopia-s-nile-dam-to-security-council-1.1016342.

Houmed, A.M. *et al.* (2012), *The Asal geothermal site, Djibouti Republic (model update 2012)*, Proceedings of the 4th African Rift Geothermal Conference, ARGeo, Nairobi, pp. 12.

HS Orka (2019), Resource Park website, www.resourcepark.is.

IEA (2017), *Energy access outlook 2017: From poverty to prosperity,* International Energy Agency, Paris.

IEA ETSAP (2010), *Technology Brief E07: Geothermal heat and power,* International Energy Agency and Energy Technology Systems Analysis Program.

IEA, IRENA, UNSD, WB, WHO (2019), *Tracking SDG7: The Energy Progress Report,* World Bank, Washington DC.

IFC (2017), *Blended finance fact sheet,* International Finance Corporation, Washington, DC.

IFC (2013), *Success of geothermal wells: A global study,* International Finance Corporation, Washington, DC.

IGA and IFC (2014), *Best Practices Guide for Geothermal Exploration* (2nd ed.), IGA Service Company GmbH, Bochum.

IGA and UNECE (2016), *Specifications for the application of United Nations Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to geothermal energy resources*, International Geothermal Association and United Nations Economic Commission for Europe, www.unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/UNFC_GEOTH/UNFC.Geothermal.Specs.pdf.

InfraCo. (2019), *InfraCo Africa presentation,* www.irena.org/-/media/Files/IRENA/Agency/Events/2018/Jan/Geothermal-financing/S5-InfraCo-Africa.df?la=en&hash=90AE7F3196FD17D953740331D9DF01A84B5091C2.

InfraCo Africa (2018), *InfraCo Africa increases its commitment to US$30 million for Ethiopia's first private geothermal project,* www.infracoafrica.com/infraco-africa-increases-commitment-ethiopias-first-private-geothermal-project-us30-million/.

IPCC (2008), *Climate change and water: IPCC Technical Paper VI*, IPCC Secretariat, Geneva, Switzerland.

IRENA (2020a), *Renewable capacity statistics 2020*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2020b), *Renewable power generation costs in 2019*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2019a), *Accelerating geothermal heat adoption in the agri-food sector*: *Key lessons and recommendations*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2019b), *Renewable power generation costs in 2018,* International Renewable Energy Agency, Abu Dhabi.

IRENA (2019c), *Renewable capacity statistics 2019*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2018), *Off-grid renewable energy solutions,* International Renewable Energy Agency, Abu Dhabi.

IRENA (2017a), *Geothermal power: Technology brief,* International Renewable Energy Agency, Abu Dhabi.

IRENA (2017b), *Renewable readiness assessment - Tanzania,* International Renewable Energy Agency, Abu Dhabi.

IRENA (2016a), *Accelerating off-grid renewable energy: IOREC 2016 key findings and recommendations,* International Renewable Energy Agency, Abu Dhabi.

IRENA (2016b), *Unlocking renewable energy investment: The role of risk,* International Renewable Energy Agency, Abu Dhabi.

IRENA (2014), *REmap 2030*, International Renewable Energy Agency, Abu Dhabi.

JICA (2014), *Data collection survey on geothermal energy development in east Africa: Tanzania final report*, JICA/WESTJEC/MMTC, Dar es Salaam.

Jolie, E. *et al.* (2009), *Geothermal potential assessment in the Virunga Prospect, Northern Rwanda, report – GEOTHERM 1*, BGR, Hannover.

Kajugus, S.I., K.T. Kabaka and T.T. Mnjokava (2018), *Geothermal development in Tanzania: A country update,* ARGeo, Kigali, pp. 9.

Kamau, M. (2019), *Power sector reforms scare investors, says report*, The Standard, www.standardmedia.co.ke/article/2001334278/changes-in-power-sector-put-off-investors-report.

Kato, K., T. Mnjokava and S. Kajugus (2016), *Geothermal development in Tanzania: A country update,* 6th African Rift Geothermal Conference, ARGeo, Addis Ababa, pp. 7.

Kaunda, C.S., C.Z. Kimambo and T.K. Neilsen (2012), *Potential of small-scale hydropower for electricity generation in sub-Saharan Africa,* Hindawi.

Kebede, S. (2016), *Country update on geothermal exploration and development in Ethiopia*, Proceedings of the 6th Africa Rift Geothermal Conference, 2-4 November 2016, ARGeo, Addis Ababa, pp. 8.

Kebede, S. and F. Woldemariam (2018), *Geothermal exploration and development in Ethiopia: Country update,* 7th African Rift Geothermal Conference, ARGeo, Kigali, pp. 9.

KenGen (2019), Centre of Excellence, www.kengen.co.ke/index.php/geothermal-center-of-excellence.html (accessed 23 December 2019).

Kenya News Agency (2020), *GDC partners with Nakuru County in offering affordable and reliable energy to farmers,* www.kenyanews.go.ke/gdc-partners-with-nakuru-county-in-offering-affordable-and-reliable-energy-to-farmers/.

Kenya-tribune (2020), *KENGEN's Olkaria geothermal plant lower evacuation costs causes competitor to lower electricity tariff,* Kenyan Tribune, www.kenyantribune.com/kengens-olkaria-geothermal-plant-lower-evacuation-costs-causes-competitor-to-lower-electricity-tariff/.

Kinyanjui, S. and M. Mburu (2012), *Cascaded use of geothermal energy: Eburru case study,* Geo-Heat Centre, Klamath Falls.

Kiptanui, S. and A. Panga (2018), *Subsidies in Kenya's geothermal sub-sector,* 7th African Rift Geothermal Conference, ARGeo-C7, Kigali, pp. 13.

KNBS (2019), *Leading economic indicators: January 2019,* Kenya National Bureau of Statistics.

Knight, B., H. Hole and T. Mills (2006), *Geothermal greenhouse heating at Oserian Farm, Lake Naivasha, Kenya,* United Nations University-Geothermalm Training Programme, Reykjavik.

Köhler, S. and A. Saadat (2003), *Thermodynamic modeling of binary cycles - looking for the best case scenarios,* International Geothermal Conference IGC 2003, Reykjavik.

LCPDP (2018), *Updated least cost power development plan study period: 2017-2037,* Republic of Kenya, Nairobi.

Legg, C.A. (1974), *Resources assessment in Zambia*, Geological Survey Department, Lusaka.

Lindal, B. (1973), "Industrial and other application of geothermal energy", in *Geothermal Energy* UNESCO, Paris.

Lugaizi, I. *et al.* (2018), *Updated structural and conceptual models for targeting temperature gradient drilling at the Panyimur Geothermal Prospect, Uganda,* 7th African Rift Geothermal Conference, ARGeo-C7, Kigali, pp. 15.

Lund, J.W. and A.N. Toth (2020), *Direct utilization of geothermal energy 2020 worldwide review*, Proceedings of the World Geothermal Congress 2020, Reykjavik, Iceland, 26 April2 May 2020.

Lund, J. and T.L. Boyd (2015), *Direct utilization of geothermal energy 2015 worldwide review,* World Geothermal Congress, International Geothermal Association, Melbourne, pp. 31.

Malimo, S. (2013). *Fluid Chemistry of Menengai Geothermal Wells, Kenya*, Proceedings of the GDC Symposium. Geothermal Development Company, Nakuru, pp.5.

Mangi, P.M. (2018), *Status of geothermal development in Kenya: A country update,* 7th African Rift Geothermal Conference, ARGeo, Kigali, pp. 23.

Mangi, P. (2013), *Direct utilisation in Kenya: A case of a geothermal spa and demonstration centre at Olkaria, Short Course VIII on exploration for geothermal resources*, UNU-GTP-KenGen-GDC, Naivasha, pp. 14.

Mariita, N., S. Onyango and J. Varet (2016), *Potential for small scale direct applications of geothermal fluids in Kenya's Rift Valley–An update from Geopower Africa Project,* Proceedings of the 6th African Rift Geothermal Conference 24 November 2016, ARGeo-UN Environment, Addis Ababa.

Mburu, M. (2014), *Geothermal energy utilization at Oserian Flower Farm-Naivasha,* UNU-GTP, Reykjavik.

Melaku, M., S. Thompson and T. Mills (1995), *Geothermal heat for sterilisation,* World Geothermal Congress, International Geothermal Association, Istanbul, pp. 4.

Menzella, A. *et al.* (2020), *Report on mitigation measures: Adopted solutions and recommendations to overcome environmental concerns,* GEOENVI.

Ministry of Energy (2012), *Feed-in tariffs policy on wind, biomass, small-hydro, geothermal, biogas and solar resource generated electricity*, Government of Kenya, Nairobi.

Ministry of Infrastructure - Rwanda (2019), *Energy sector*, www.minecofin.gov.rw/fileadmin/templates/documents/NDPR/Joint_Sector_Review/Forward_Looking_JSRs/Forward_Looking_JSR_2019-20/Energy_Sector_FLJSR.PDF.

Ministry of Water and Energy (2012), *Scaling up renewable energy programme, Ethiopia investment plan,* Federal Democratic Republic of Ethiopia, Addis Ababa.

Mnjokava, T., K. Kabaka and J. Mayalla (2015), *Geothermal development in Tanzania – A country update,* World Geothermal Congress, International Geothermal Association, Melbourne, pp. 6.

Moeck, I.S. and G. Beardsmore (2014), *A new 'geothermal play type' catalog: Streamlining exploration decision making*, Proceedings of the Thirty-Ninth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, pp. 8.

Mohamed, O.A., K. Mousa and A. Khaireh (2016), *Geothermal development in the Republic of Djibouti: A country update report,* 6th African Rift Geothermal Conference, ARGeoC6, Addis Ababa, pp. 16.

Moussa, O.A. and H. Souleiman (2015), *Country report, geothermal development in Djibouti Republic,* World Geothermal Congress 2015, International Geothermal Association, Melbourne, pp. 5.

Nalule, V.R. (2016), *Energy in the East African community: The role of the Energy Charter Treaty*, Energy Charter Secretariat, Brussels.

Natukunda, J.F. and G. Bahati (2018), *Preliminary exploration of geothermal energy of Buranga Prospect, Uganda,* 7th African Rift Geothermal Conference, ARGeo-C7, Kigali, pp. 15.

Nebro, A. *et al.* (2016), *Community-based geothermal development perspective in Afar: A new player Afar Geothermal Development Company (AGAPI)*, Proceedings of the 6th African Rift Geothermal Conference, 24 November 2016, Addis Ababa.

New Zealand Geothermal Association (2017), *Geoheat strategy for AOTEAROA NZ 20172030,* New Zealand Geothermal Association, Auckland.

Ngawha Innovation and Enterprise Park (2019), Ngawha Innovation and Enterprise Park website, Ngawha Innovation and Enterprise Park, https://ngawhapark.nz/ (accessed 18 November 2019).

Ngugi, B. (2019), *Kenya Power freeze puts new energy plant billions on the line*, Daily Nation, www.nation.co.ke/business/Kenya-Power-freeze-new-energy-plant/996-4921588-nfxdt6/index.html.

Nguyen, M. *et al.* (2015), *Uses of geothermal energy in food and agriculture: Opportunities for developing countries,* Food and Agriculture Organization of the United Nations, Rome.

Norton Rose Fulbright (2017), *Geothermal strategy, legal, institutional and regulatory framework and partial risk guarantee for development of geothermal energy resource,* Ministry of Energy and Minerals, Dar es Salaam.

NSE (2019a) *Green bond markets: Financing environmental solutions for sustainable development,* Nairobi Stock Exchange, www.nse.co.ke/products-services/debt-securities/the-green-bond.html?download=11487%3Akenya-green-bonds-training-material (accessed 14 March 2020).

NSE (2019b), *Annual report 2017-2018,* Green Bonds Programme, Nairobi Stock Exchange, www.nse.co.ke/products-services/debt-securities/the-green-bond.html?download=11515%3Agreen-bonds-annual-report (accessed 14 March 2020).

Nyambura, E. (2016), *Direct use of geothermal energy: Menengai direct use pilot projects in Kenya*, 6th African Rift Geothermal Conference, 2-4 November 2016, ARGeo, Addis Ababa, pp. 9.

NZ-AGF (2020), *East Africa geothermal activities,* New Zealand-Africa Geothermal Facility.

OECD (2003), *Glossary of statistical terms: Concessional loans,* Organisation for Economic Cooperation and Development, https://stats.oecd.org/glossary/detail.asp?ID=5901.

Omenda, P.A. (2018), "Overview of the existing geothermal risk mitigation schemes in eastern Africa"*, GRC Transactions 42*, Geothermal Resources Council, Reno, pp. 9.

Omenda, P. and P. Mangi (2016), *Country update report for Kenya – 2016,* 6th African Rift Geothermal Conference , ARGeo, Addis Ababa, pp. 14.

Omenda, P. and S. Simiyu (2015), *Country update report for Kenya: 2010-2014*, World Geothermal Congress, International Geothermal Association, Melbourne, pp. 11.

Omenda, P. and M. Teklemariam (2010), *Overview of geothermal resource utilization in the East African Rift system: Short Course V on exploration for geothermal resources,* UNU-GTP-GDC-KenGen, Naivasha, pp. 11.

Omenda, P. and M.T. Zemedkun (2011), *Overview of geothermal resource utilization in the East African Rift system: Short course UNU-GTP-KenGen-GDC*, UNU-GTP, Naivasha, pp. 10.

Omenda, P. *et al.* (2020), *Country update report for Kenya 2015-2019*, World Geothermal Congress 2020, International Geothermal Association, Reykjavik, pp. 16.

Omenda, P. *et al.* (2016a), *Characteristics and important factors that influence the development of geothermal systems in the western branch of the East African Rift system,* 6th African Rift Geothermal Conference, ARGeo, Addis Ababa, pp. 17.

Omenda, P. *et al.* (2016b), *Technical workshop on the geologic development and geophysics of the western branch of the greater East African Rift system,* African Rift Geothermal Conference Workshop, ARGeo, UNEP, Kigali, pp. 61.

Onyango, S. and J. Varet (2018), *Proposing a new, specific methodological approach to medium enthalpy shallow geothermal resources for Africa's Rift Valley,* Proceedings of the 7th African Rift Geothermal Conference, 31 October2 November 2018, ARGeo, UN Environment, Kigali.

Parhelion (2020), *Parhelion Underwriting awarded P4G grant and partnership for GeoFutures GreenInvest,* 19 May press release, https://parhelion.co.uk/geofutures-greeninvest-press-release/.

Parhelion Underwriting Ltd. (2019), *GeoFutures fund managers Environmental and Social Management System (ESMS),* www.parhelion.co.uk/wp-content/uploads/2019/06/GeoFutures-ESMS-Final-V1-190613_Clean.pdf.

PIDA (2020), Virtual PIDA information centre, Programme for Infrastructure Development in Africa, www.au-pida.org/pida-projects/.

Ram, H. (2018), *Short-term vs. long-term geothermal resource risk and mitigation,* Proceedings of the 7th African Rift Geothermal Conference, 31 October2 November 2018, Kigali, Rwanda.

REPP (2020), *Bweengwa, Zambia*, Renewable Energy Performance Platform, https://repp.energy/project/geothermal-project-bweengwa-zambia/.

RG (2017), *The Government of Ethiopia and Ethiopian Electric Power sign key agreements with Corbetti Geothermal plc.*, Reykjavik Geothermal, www.rg.is/en/frettir/the-government-of-ethiopia-and-ethiopian-electric-power-sign-key-agreements-with-corbetti-geothermal-plc.

Ring, U. (2014), "The East African Rift system"*, Austrian Journal of Earth Sciences*, Vol. 107, pp. 132-146.

Robertson-Tait, A. *et al.* (2017), *The GeoFutures Facility: A proposed geothermal risk mitigation instrument for East Africa*, Geothermal Resources Council.

Samans, R. (2016), "Blending public and private funds for sustainable development", in *Development Cooperation Report 2016: The Sustainable Development Goals as business opportunities,* OECD Publishing, Paris.

Sanders, M. (2015), *Regulatory framework conditions for geothermal direct use projects in France, Germany, Iceland, Sweden and Turkey,* World Geothermal Congress, Melbourne.

SAPP (2020), *SAPP members,* Southern African Power Pool, www.sapp.co.zw/about-sapp#members.

SAPP (2017), *SAPP pool plan 2017*, Southern African Power Pool, Harare.

Shalev, E. *et al.* (2012), *Geoscientific surveys of the Rwandan Karisimbi, Gisenyi and Kinigi Geothermal Prospects. Final report,* Institute of Earth Sciences and Engineering, University of Auckland, Auckland.

Smith, C. *et al.* (2018), *Sharing best practices in community engagement for geothermal development – Kenya/New Zealand partnership,* Proceedings of the 7th African Rift Geothermal Conference, 31 October2 November 2018, Kigali, Rwanda.

Sussman, D. (2018), *IRENA workshop: Lessons from EAGER*, Regional workshop on Geothermal Financing and Risk Mitigation in Africa, International Renewable Energy Agency, Abu Dhabi.

Takouleu, J. (2020), *Ethiopia: Tulu Moye geothermal project receives $10 million loan from CTF*, Afrik21, www.afrik21.africa/en/ethiopia-tulu-moye-geothermal-project-receives-10-million-loan-from-ctf/.

Teklemariam, M. and K. Beyene (2005), *Geothermal exploration and development in Ethiopia,* World Geothermal Congress, Antalya, Turkey, International Geothermal Association, pp. 9.

Tesfaye, E. (2014), EAPP profile. https://pubs.naruc.org/pub.cfm?id=5388F6DB-2354-D714-516F-A8C30F137BA4

TGDC (2017), *Geothermal resources project proposal document for Tanzania,* Tanzania Geothermal Development Company, Ministry of Energy and Minerals, Dar es Salaam.

UNECA (2019), *Fiscal policy for financing sustainable development in Africa: Economic report on Africa*, United Nations Economic Commission for Africa, Addis Ababa.

UNECE and IGA (2016), *Specifications for the application of the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009) to geothermal energy resources,* United Nations Economic Commission for Europe and International Geothermal Association, Geneva.

UNEP (2015), *A skills audit and gap study for the geothermal energy subsector in African countries,* United Nations Environment Programme, Nairobi.

UNFCCC (2019), NDC Registry: All NDCs, United Nations Framework Convention on Climate Change, www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx (accessed 11 August 2020).

UNStats (2019), SDG Indicators, United Nations Statistics Division, https://unstats.un.org/sdgs/indicators/database/ (accessed 1 December 2019).

USAID (2019), *Malawi: Power Africa fact sheet*, United States Agency for International Development, Washington, DC, www.usaid.gov/powerafrica/malawi.

USAID (2013a), *Priority geothermal direct-use applications for Kenya: A pre-feasibility study for aquaculture*, United States Agency for International Development, Washington, DC.

USAID (2013b), *Priority geothermal direct-use applications for Kenya: A pre-feasibility study for crop drying*, United States Agency for International Development, Washington, DC.

Varet, J. (2018a), *Geothermal resource along the border: The Ethiopia - Djibouti case,* 7th African Rift Conference, Kigali, pp. 12.

Varet, J. (2018b), *Geothermal resources along borders: The Rwanda - DRC case,* Proceedings of the 7th African Rift Conference, ARGeo-7, Kigali, pp. 14.

Varet, J. *et al.* (2014), *The "Geothermal Village" concept,* Proceedings of the 5th African Rift Geothermal Conference, ARGeo-UN Environment, Arusha, Tanzania.

Vivian-Neal, P. *et al.* (2018), *Zambia: Exploration of the non-volcanic, fault hosted Bwengwa River geothermal resource area,* Proceedings of the 7th African Rift Conference, ARGeo-7, Kigali, pp. 12.

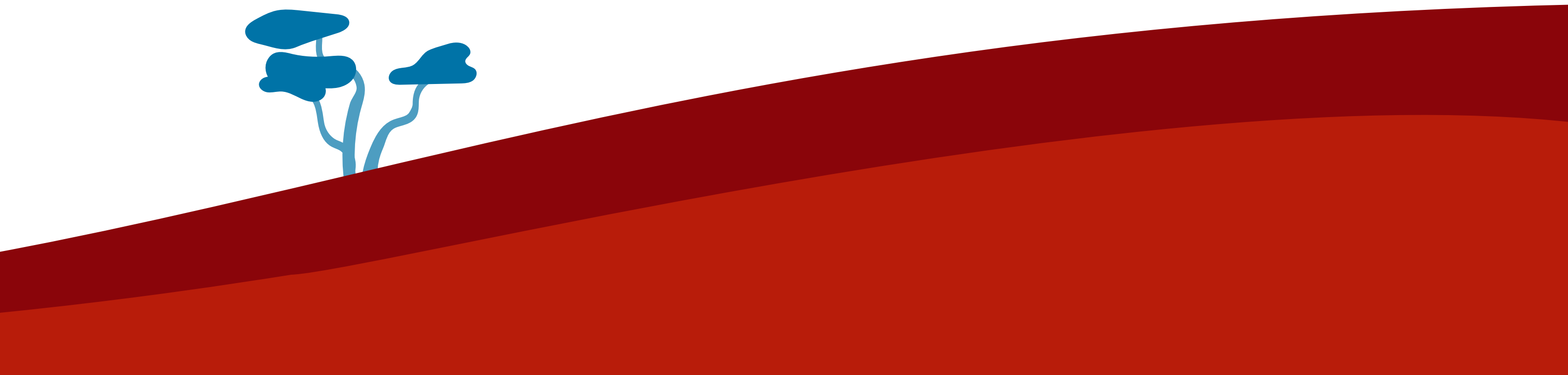
World Bank (2020), GDP per capita, PPP (current international $) https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD (accessed 16 September 2020).

World Bank (2019b), Population, total - Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia, Burundi (database), https://data.worldbank.org/indicator/SP.POP.TOTL?locations=DJ-ER-ET-KE-MW-MZ-RW-TZ-UG-ZM-BI (accessed 14 July 2019).

World Bank (2018), *Kenya charts path to achieving universal access to electricity*, www.worldbank.org/en/news/feature/2018/12/06/kenya-charts-path-to-achieving-universal-access-to-electricity (accessed 8 December 2019).

World Bank (2017), *Djibouti: Sustainable electrification program*, https://documents.worldbank.org/en/publication/documents-reports/documentdetail/313651499406590142/djibouti-sustainable-electrification-program-project.

Yewondwossen, M. (2017), *EEP, Corbetti Geothermal ink first power purchase agreement*, Capital, www.capitalethiopia.com/featured/eep-corbetti-geothermal-ink-first-power-purchase-agreement/.



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