The African Continental Power Systems Masterplan

Support Studies – Geothermal Power Plants (GPP)

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Introduction

Development of a continental master plan

The African Union (AU) has articulated a vision for a continent-wide interconnected power system (the Africa Single Electricity Market (AfSEM)) that will serve 1.3 billion people across 55 countries, making it geographically the biggest electricity market in the world. Interconnection offers immense technical and economic opportunity[1], while a fully integrated and competitive market will accelerate development and energy access across the continent. Increasingly, the enhanced system flexibility and resilience of an interconnected power system is also an imperative for a modern power system able to navigate the developments impacting global energy systems. This includes growing shares of low-cost variable renewable energy; commitments to climate change and decarbonisation, decentralisation and democratisation of energy; intelligent grid infrastructure and digitalisation of the energy sector; infrastructure resilience in the face of climate risks; and the rise in energy storage technology and electric vehicles.

Concrete steps have been taken towards realising the broader vision described by the AfSEM together with the AfDB's new deal for energy and clean energy corridor concepts. Among these is the development of a Continental Power System Masterplan (CMP) expected to create the framework conditions that will allow countries to trade electricity to leverage national and regional surpluses and deficits through cross border power exchanges and inter power pool trade. This harmonized platform will aid optimised project decision-making regarding the location, size and timing of generation and transmission infrastructure investments.

The CMP is being developed under the governance structure of AUDA-NEPAD (African Union Development Agency) with direction from ministerial committees to ensure political and technical alignment. Development of the CMP spans two phases (Figure 1) and is implemented over several years, with targeted completion of the first draft by the end of 2023.

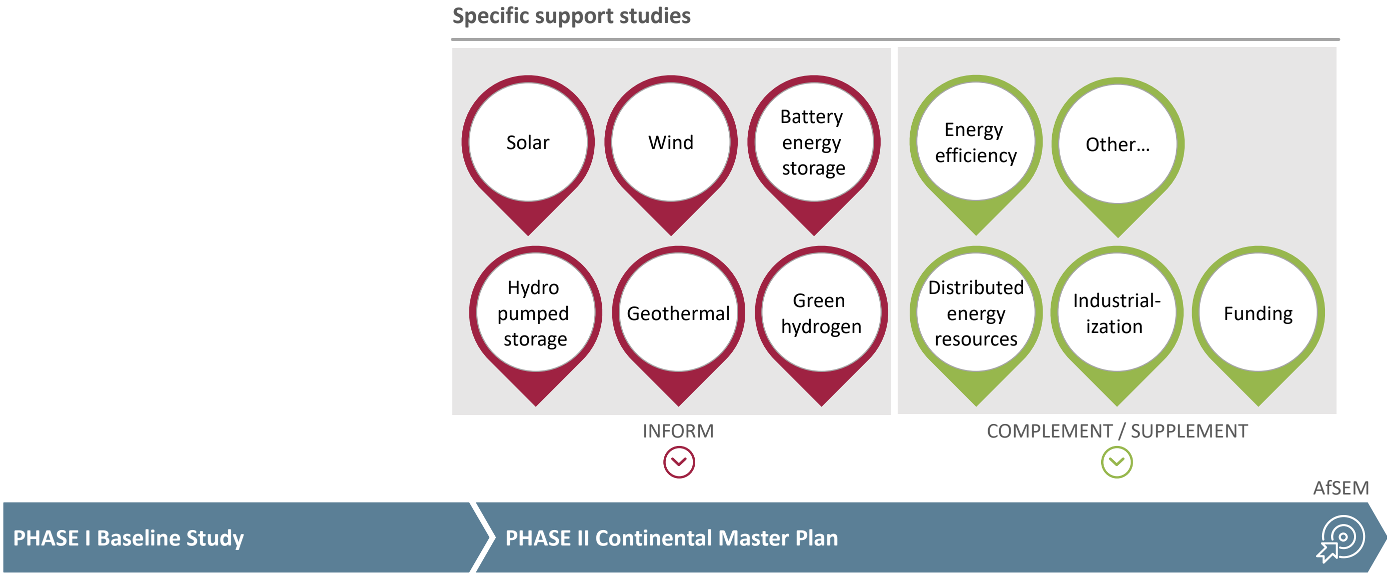


Figure 1: CMP development phases with input from specific support studies

[1] Benefits include increased system reliability; access to more diverse generation resources; enhanced security of supply; improved system flexibility, redundancy, and resilience; reduced or deferred capital investments; diversified loads and improved load factors; and operational and maintenance efficiencies gains, among others.

In parallel, several studies are being developed to help refine and enhance the CMP (Figure 1). These specific support studies (SSS) aim to inform or complement the planning of the CMP, providing a clearer understanding of the potential contribution to the continental power system or the potential for adjacent developmental opportunities.

Geothermal as part of the energy generation mix

This study focuses on the findings of the geothermal power SSS which was developed with support from the European Union Technical Assistance Facility (EU-TAF) for Sustainable Energy. It provides an overview of the identified resource potential, opportunities, barriers or challenges and recommendations to achieve an optimal contribution to the CMP.

Global projections to 2040 recognise renewable energy – including geothermal power – as a critical part of a diversified electricity mix to meet the power needs of the world (Figure 2).

The CMP being developed for the African continent show geothermal power grow from 0.7% in 2023 to 1.1% of the electricity mix planned for 2040.

Current planning for the future diversified energy mix supports the expansion of geothermal power plants (GPP) to countries with a high potential but with little to no existing generation.

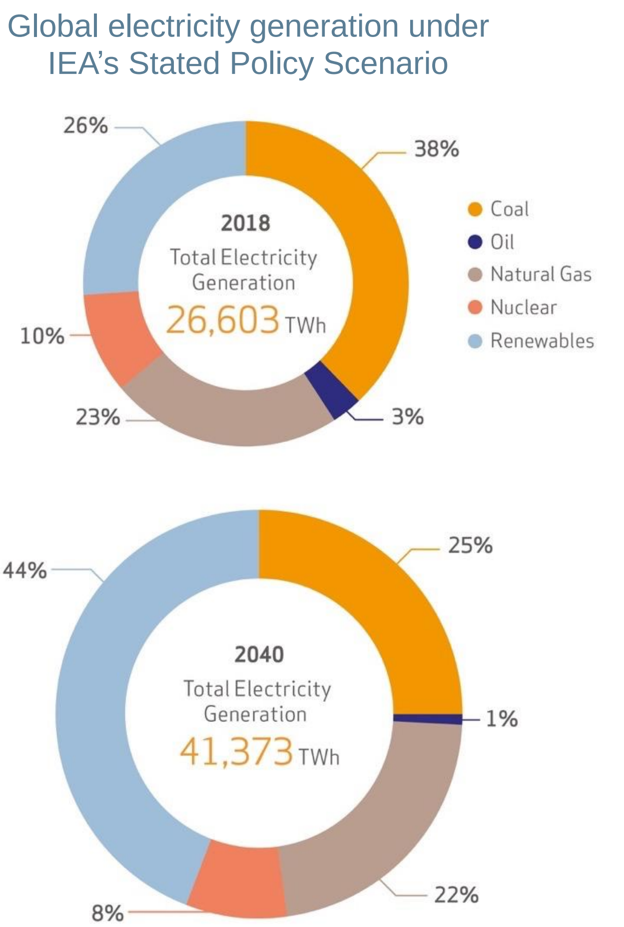


Figure 2: Changes in the global electricity mix[2], 2018 – 2040 (measures in TWh)

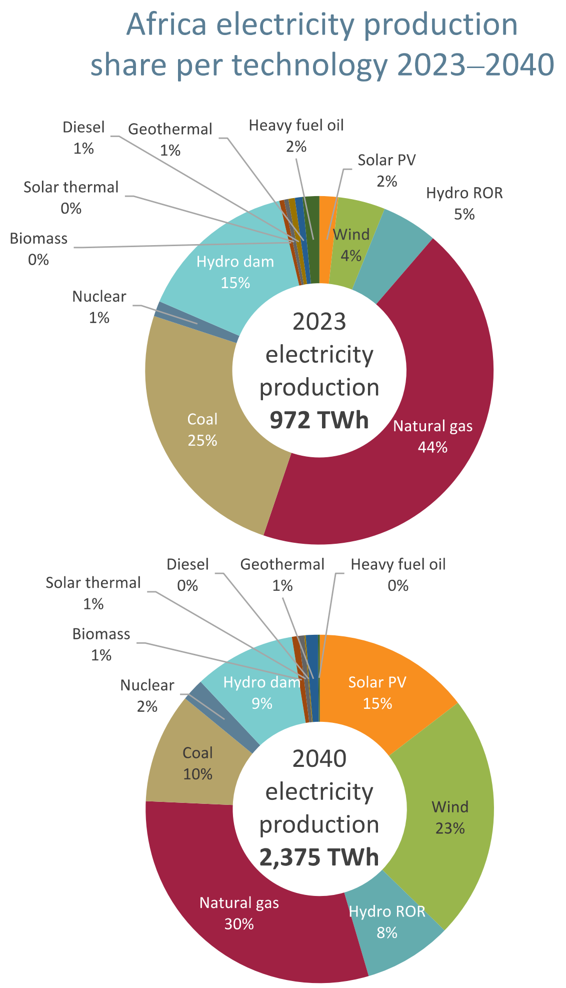


Figure 3: Africa electricity production share per technology 2023–2040

[2] International Energy Agency (IEA) World Energy Outlook, 2019 data

Resource potential

Overview

Geothermal is a type of renewable energy taken from the earth's core. It comes from heat generated during the original formation of the planet and the radioactive decay of materials. This thermal energy is stored in rocks and fluids in the centre of the earth. The difference between the temperature in the earth's core and its surface drives a continuous conduction of thermal energy from the interior to the exterior, where the rock and water in the earth's crust can reach temperatures as high as 370°C. The thermal energy contained in these rocks and fluids can be found from shallow depths right down to several miles below the earth's surface.

Geothermal is one of the earliest forms of energy harnessed by humans – it has been used for bathing since the Paleolithic times and for space heating by the ancient Romans. With technological advances, this almost inexhaustible source of energy, was first used to produce electricity in 1904 and the global installed capacity reached ~16GW in 2021. Geothermal energy is also used directly, by piping thermal water for heating greenhouses, fish farms, and municipal heating systems. Geothermal heat pumps can be installed almost anywhere and are widely considered the best way of heating and cooling homes

Geothermal systems can be divided into low, medium or high enthalpy[3], depending on the geothermal gradient[i4] of the area. The systems with the greatest potential for energy production are in areas where the geothermal gradient is higher than average (30ºC/km). These systems are scattered along the plate boundaries where the thermal anomaly is felt with greater intensity and at a shallower depth (**Error! Reference source not found.**4).

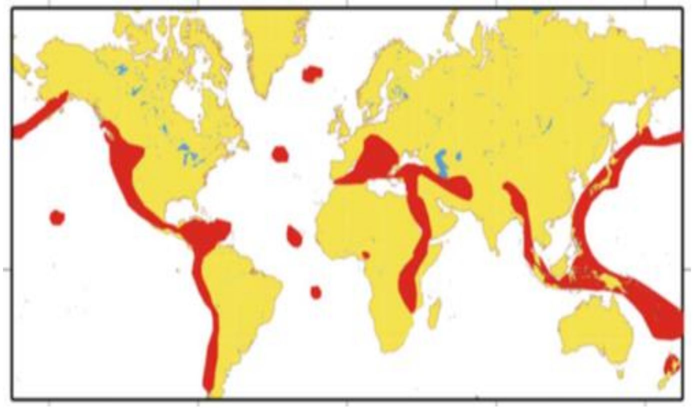


Figure 4: World geothermal regions

As can be seen from Figure 4, in Africa GPPs would be situated on the East African Rift System (EARS). Here, a distinction must be made between the countries with the greatest GPP potential, located on the boundaries of tectonic plates where the heat source is closer to the surface, the eastern branch (EB) of the EARS: Ethiopia, Eritrea, Djibouti, Kenya, Somalia, and Tanzania (north). Countries located on the western branch (WB) -Burundi, Uganda, Rwanda, Tanzania (west), Malawi, Mozambique, Zambia and DRC are better suited for direct use projects (Figure 5). The study is limited to GPP and does not consider direct heating.

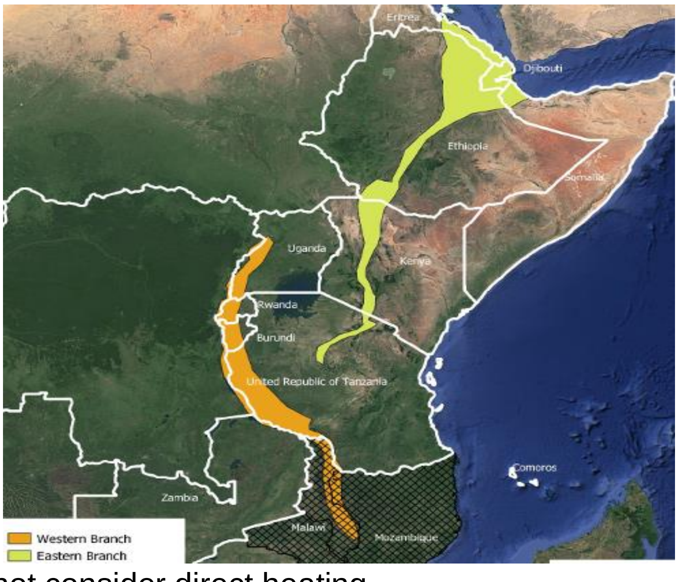


Figure 5: The East African Rift System (EARS)

[3] The measurement of energy in a thermodynamic system

[4] The geothermal gradient is defined as the increase in temperature with depth in the Earth. In normal continental crust a typical geothermal gradient within the first 3 to 5 kilometers of Earth's surface is about 25°-30°C/km

GPP Potential and Performance

Although an established energy source, geothermal has shown especially strong growth since 2009 with a 65.1% compound annual growth rate. Global decarbonization efforts will continue to drive this growth and geothermal is expected to play an increasingly bigger role in regions with active volcanism and along plate boundaries. Globally, the US has the biggest installed capacity (3.7GW), followed by Indonesia (2.3GW) and the Philippines (2.2GW). Kenya and Italy are the seventh biggest at ~0.95GW. The only other country in Africa with GPP capacity is Ethiopia with 8.5MW. The DRC and Zambia have small historic GPP but neither are operational.

It is estimated that east Africa has a total GPP potential of between 15 and 20GW. Currently, the total installed capacity is ~1GW making this a largely underexploited energy resource. An assessment of country's with existing and planned GPP capacity (excluding direct use which has different applications) is summarised in the table below. No evidence of formal government policy or resource assessments was found for DRC and Eritrea, and are therefore not included.

The main GPP production technologies:

1. Dry steam: takes steam directly from fractures in the ground to drive a turbine

2. Flash steam: Globally, this technology dominates and comes in two forms: i) Single: pulls high pressure hot water from underground which is mixed with cooler low pressure water. This creates steam that is used to drive a turbine; ii) Double: Same principle but with two separators, allowing for high and low-pressure steam flows. This technology is more efficient and delivers higher capacity, but costs more. Despite the improved performance it is not economically feasible for certain locations and applications

3. Binary (Organic Rankine Cycle): hot water passes through a secondary fluid that has a lower boiling point than water. The secondary fluid is converted to vapour to drive a turbine. Future GPPs are expected to be binary as they operate at a wider temperature range and have a lower environmental impact.

Country	Installed capacity 2021 (MWe)	Under construction/ development (MWe)	Targets 2030 / 2040	Estimated maximum potential	Observations
Djibouti (EB)	-	-	N/A	1 GWe	22 GPP areas identified and prioritized.
Ethiopia (EB)	8	70 (Aluto) 2 x 150 (Corbetti and Tulu Moye)	1 GWe by 2030	5-10 GWe	Expand existing plant to 70MW but experiencing operational challenges. Power purchase agreement for Corbetti and Tulu Moye signed.
Kenya (EB)	986	328 (105 + 140 + 83)	2 GWe 3 GWe	7-10 GWe	Geothermal is used as baseload. Installed GPP represents 1/3rd of total capacity
Tanzania (W&EB)	-	-	200 MWe	0.5-5 GWe	Still at the exploration stage.
Uganda (WB)	-	-	N/A	0.45 GWe	Three sites identified, delayed due to technical issues and awaiting environmental and social impact assessment.
TOTAL	**994**	**698**	**3-5 GWe**	**15-20**	

Opportunities and Costs

The primary advantages of geothermal energy are its low cost and its ability to operate throughout the year at high capacity factors i.e reliable and affordable baseload supply. These features facilitate the provision of firm dispatchable electricity to the grid as well as providing ancillary support services to the grid, which is especially useful to grids shifting to variable renewable energy technologies. The International Renewable Energy Agency (IRENA) estimates the levelized cost of electricity (LCOE) from geothermal power projects averaged between USD 0.049 and USD 0.085 per kWh between 2010 and 2020.

However, as with all energy sources, geothermal has some drawbacks. These include, as already mentioned, that generation is limited to areas near tectonic plate boundaries, and as such strong geothermal resources may prove uneconomic if too deep or too far from demand or transmission lines. Plants may cool down after decades of use, release hydrogen sulphide and / or discharge low levels of toxic materials which must be managed. Developers must also act responsibly with regards sensitive environmental sites, indigenous land and take care to not exploit illiterate communities to access prime sites. Finally, inasmuch as this power is cheaper once the plant is operational, the upfront drilling and exploration costs are lengthy and expensive. - GPPs consist of three phases and take up to five years to complete (**Error! Reference source not found.**).

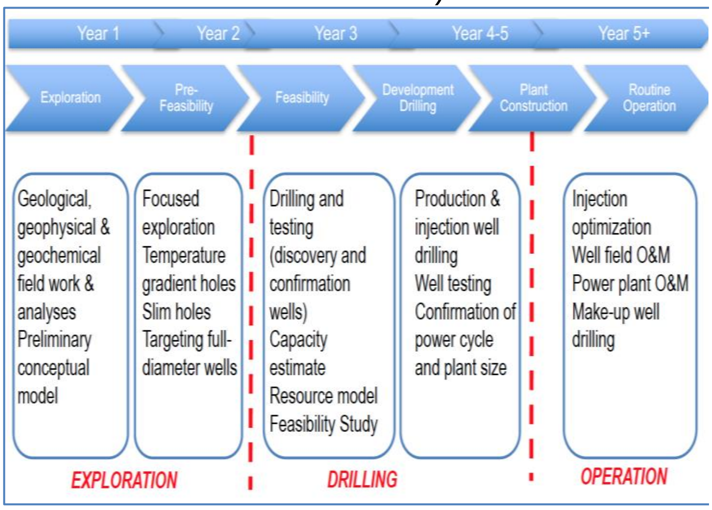


Figure 6: GPP development phases and duration

The exploration phase is an especially high risk activity and becomes a sunk cost if the potential of the geothermal resource is not sufficient or suitable for GPP development. The project's risk profile is reduced only after the test drilling phase is complete and positive.

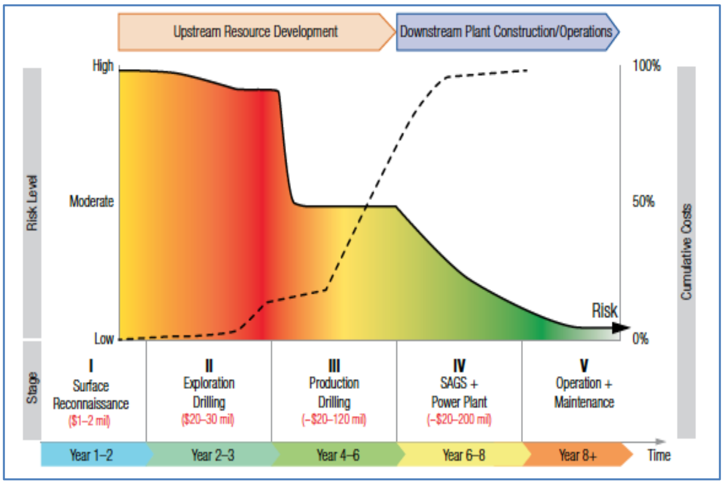


Figure 7: Risks and costs in GPP development

The high upfront costs and risk associated with GPP must be considered in the context that this technology competes with other power generation sources and technologies that may be cheaper, easier to deploy, offer higher certainty and flexibility. Thus, countries endowed with significant hydro and natural gas resources may not have a strong incentive to develop GPP despite the listed advantages of high-capacity factor, baseload supply and low operating expenses (OPEX).

Finance, Regulatory and Technical Implementation Barriers

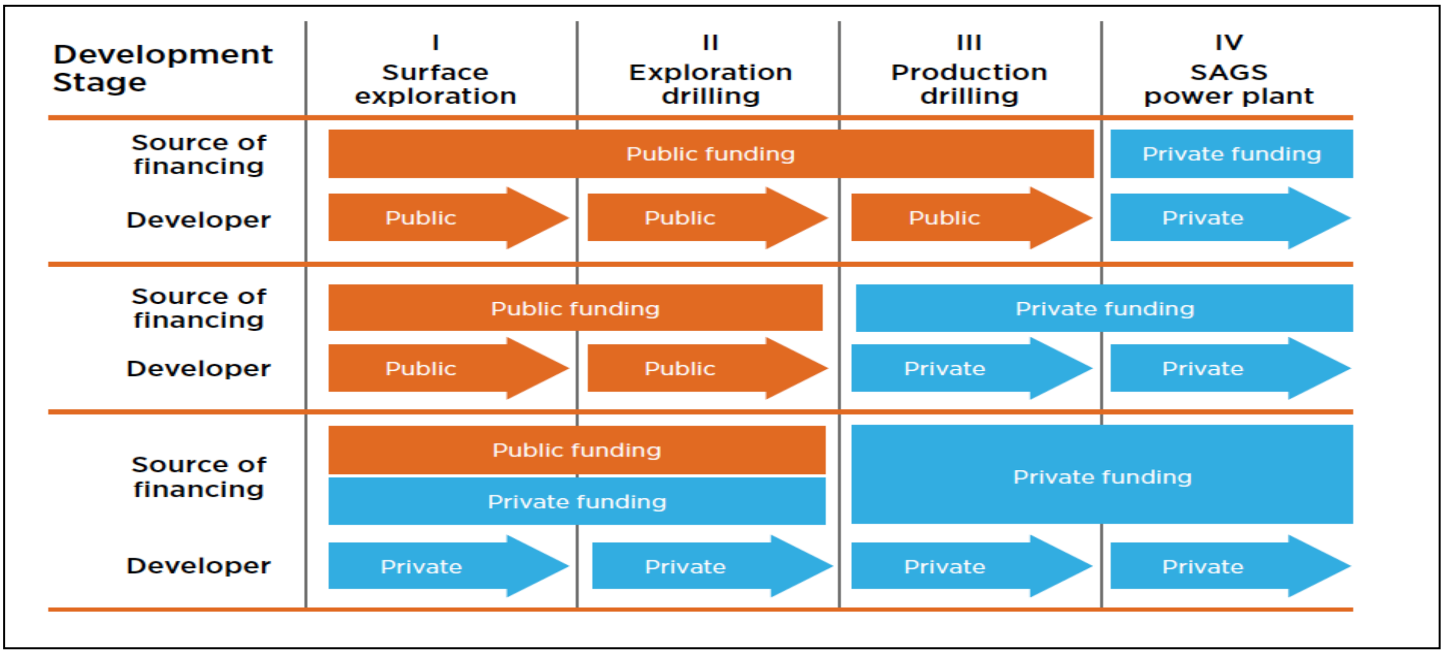
With over one third of its total capacity derived from geothermal, 328MW under construction and a stated target of up to 10GW by 2040 Kenya is not only an African, but a global leader. This is attributed to clear policy direction and taking actions which have reduced risks for private investors by establishing adequate and transparent legal, institutional, and regulatory frameworks. The President pledged to keep developing this geothermal capacity and move to 100 percent clean energy by 2030. Key actions include:

- The geothermal development company (GDC) was established in 2008 to identify and develop resources to reduce high upfront risks, costs and facilitate private sector participation
- A feed in tariff was introduced in 2008, revised in 2012 and 2021 (USD 0.065/kWh)
- National and international legal and regulatory guidelines have been introduced to ensure sustainability is in place, such as World Bank Safeguard Policies.

Kenya, who first started deploying geothermal in the 1980s, has grown its capacity from 15MW to 950MW, and this experience not only accelerates the development of new GPPs but allows it to provide the region with technical assistance.

However, as demonstrated in the Table in the previous section, meaningful GPP development is limited to Kenya and the region's full potential is unlikely to be exploited until the identified barriers are addressed by the respective governments. Establishing adequate and transparent legal, institutional, and regulatory frameworks are crucial, and include:

- Customised legal and licensing dispositions as existing laws are typically inadequate
- Clear and balanced risk-sharing schemes that ensure a return on investment



- Feed in Tariffs are a necessary but insufficient incentive for GPP development
- To be 'bankable', projects require an implementation and power purchase agreement
- The establishment of dedicated geothermal offices to assist prospective project developers. This has the dual role of creating local expertise and reducing administrative burden.

Most importantly however, government must be seen to take the lead and create a conducive environment for GPP investment, as has been demonstrated by the Kenyan experience.

Commercial banks are unlikely to fund project exploration phases. Addressing this barrier requires pre-feasibility activities to be undertaken / supported by government to demonstrate commercial viability, and most especially for new projects. However, this is only possible if the necessary investments are made to ensure that the required levels of technical capacity and authority is present.

Different business models and levels of cost-sharing between the private and public sector can be considered to overcome the high cost and high-risk profile of the exploration stage. Private developers can enter the project at different stages depending on (i) size and characteristics of geothermal resource, (ii) government technical and financial capacity, (iii) level of private sector interest, (iv) tariff regime and (v) regulatory environment. The following three models have been used successfully in Kenya.

Conclusion

As much as 20GW of potential electricity generation is available to countries situated within the EARS, and this excludes direct use for industrial and commercial applications. To date only 1GW, roughly 5% of the total has been harnessed. Geothermal offers multiple benefits including high capacity factors and low costs. However, the initial development of these projects presents considerable challenges and risks both in terms of resource exploration and fund raising. The high costs of drilling exploration with no guarantee of the estimated potential during the surface exploration phase discourages many private investors and developers.

Countries are at different levels of development and exploitation of geothermal energy, with Kenya the most advanced having grown its installed capacity from 15MW to 950MW and actively pursuing an increase to 10GW by 2040. Ethiopia has recently initiated efforts to develop large GPP, with investment in drilling campaigns in several geothermal fields to confirm their potential. Djibouti, Tanzania and Zambia are taking their first steps by undertaking surface evaluations and sinking exploration wells to estimate the potential. The DRC and Eritrea are still to consider and develop conducive policy. Ultimately, reducing some of the upfront project risk is a pre-condition to attracting the private investment needed to unlock these opportunities.

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i