Fact sheet for geothermal development to promote Public Private Partnerships in East Africa

Ethiopia

Overview of electricity sector status

Ethiopia currently has a total power generation capacity of 5,274.97 MW. The largest share of this installed capacity is from hydro power at 91%, wind 0.06%, while biomass and diesel plants account for 2.03% and 0.51%, respectively (Ethiopian Electric Power, 2023), (Table1).

Table 1: Installed electricity capacity in Ethiopia

No	Source of generation	Installed capacity (MW)	%
1	Hydropower	4,818.3	91.3
2	Wind	324	6.14
3	Geothermal	8.5	0.16
4	Thermal (Diesel and HFO)	99.17	1.9
5	Waste to energy (WtE)	25	0.47
	Total	**5,274.97**	

In 2023, the national level of electricity access in Ethiopia was 51.9%. The access rate in the rural areas was still very low with only 8% of rural households connected to the grid. The level of access in the urban areas was 92% (Africa Clean Energy Technical Assistance Facility, 2022). Under the national electrification program, it has been planned to reach 100% by 2025. The energy policy of the country is to ensure reliable supply of energy at the right time at affordable prices in support of agricultural and industrial development. The strategy is to produce all electricity from hydropower, geothermal, wind, solar, and other renewable resources, promote energy efficiency, and reduce the role of hydrocarbon fuels in transport and industry. Future generation plan includes tens of thousands of MWs from various renewable sources. From these, a 70 MW geothermal plant is planned for construction at Aluto Langano geothermal project by EEP and a total of 3500 MW geothermal is planned by year 2030 (Table2). However, this plan is over ambitious and may not achievable within the timeframe.

Table 2: Table of current and planned generation expansion in Ethiopia

Source of Energy	Existing Capacity (MW)	Target Capacity for 2025 (MW)	Target Capacity for 2030 (MW)	Ongoing Projects (MW)	
				Under Construction	Under Preparation
Hydropower	4,818.3	10,817	20,200	8,804	2,280
Geothermal	8.5	170	3,500	(5MW pilot completed)	70
Solar	0	300	3,000		100 (auctioned) 450 (EOI)
Wind	324	1,224	2,500	120	Multiple Project Preparation
Nuclear	0	0	2,000		Under study
Waste to Energy	25	0	300		
Other Sources (Diesel)	99.17	1,290	1,580	170	
Total	**5,275**	**14,208**	**33,080**	**9,164**	**3,130**

Source: (Ethiopian Electric Power, 2023); (African Energy Chamber, 2022)

Figure shows grid-connected installed electricity capacity trends in Ethiopia by source from 2010 to 2021 (IRENA, 2022). As of 2021, the installed capacity connected to the Ethiopian grid is about 4,840 MW, of which about 8.5 MW is geothermal, which is only 0.15% of the total. Since 2017, the installed capacity of electricity has increased rapidly, mostly due to hydropower build-up and renewable energy sources which contributed about 98% of the total grid-connected installed electricity capacity in 2021. Conversely, the installed capacity of fossil fuel-derived thermal power has been declining since around 2015, accounting for 2% of total installed capacity in 2021.

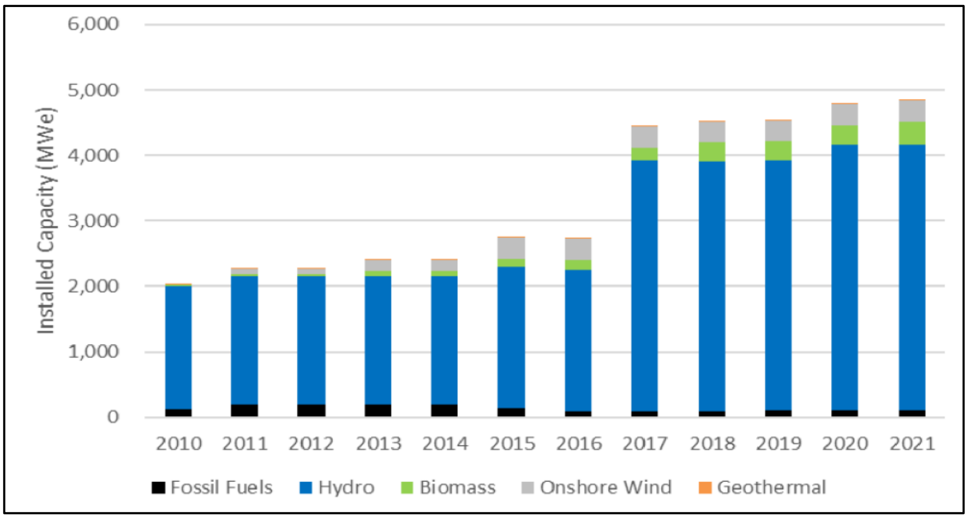

Figure 1: Grid-connected installed electricity capacity trends in Ethiopia by source

Data Source: (IRENA, 2022)

As shown in Figure2, Ethiopia's electricity generation has been increasing year by year, with the increase being met by hydropower, which accounted for 94% of electricity generation in 2019. Ethiopia's only geothermal power plant with operational experience, Aluto-Langano (8.5 MW), has not been operational since 2015.

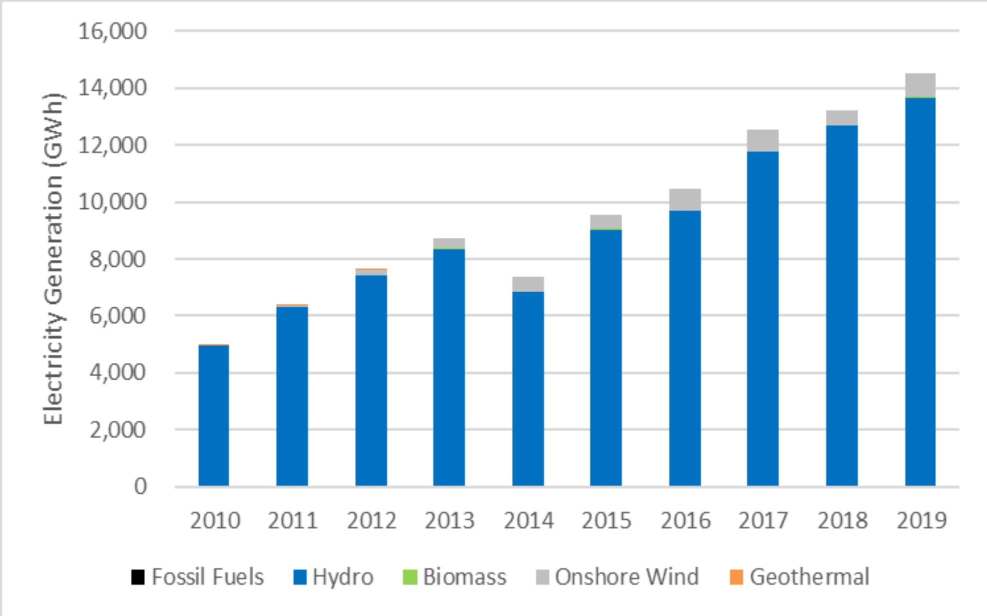

Figure 2: Grid-connected electricity generation trends in Ethiopia by source

Data Source: (IRENA, 2022)

The power purchase tariff rates for geothermal projects under implementation in Ethiopia are 0.0695 US$ cents/kWh and 0.0753 US$ cents/kWh for Tulu Moye and Corbetti geothermal projects, respectively. In comparison, solar projects without storage have a Power Purchase Agreement (PPA) of 0.02526 US$ Cents/kWhr. Consumer electricity retail tariff in Ethiopia is categorised for different consumers with residential having rates between 0.273 to 2.481 ETB/kWh1 (Ethiopia Electricity Utility, 2022). Industrial consumer rate varies from 0.928 to 2.124 ETB/kWh and accompanying varying demand charge rate of between 87.64 – 200 ETB/kWh depending on the consumption and peak demand.

Overview of geothermal development status

Geological setting

Ethiopia is endowed with large geothermal potential with most of the resources located in the Ethiopian Rift Valley which is part of the East African Rift System. The Ethiopian Rift Valley is a region of high heat flow anomaly due to upper mantle intrusion beneath a thinned crust and presence of shallow magma bodies under the Quaternary volcanoes. Along the rift occurs Quaternary central volcanoes some of which have calderas while fissure eruptions are more common in the north where extension is highest. The geothermal areas are closely associated with the areas of Quaternary volcanism within the axis of the rift. Exploration for geothermal resources for power generation started in about 1969 and continued to date with detailed studies and exploration drilling at several

[1] Exchange rate US$1=ETB55.00

sites. However, use of geothermal resources in Ethiopia is dated from the time of Emperor Menelik II in 1880's when he setup Addis Ababa city at Filwoha hot springs. The springs are still in use to date for wellness bath. The studies undertaken between 1969 and 2022 established the occurrences more than 26 high temperature geothermal sites within the rift (Figure3).

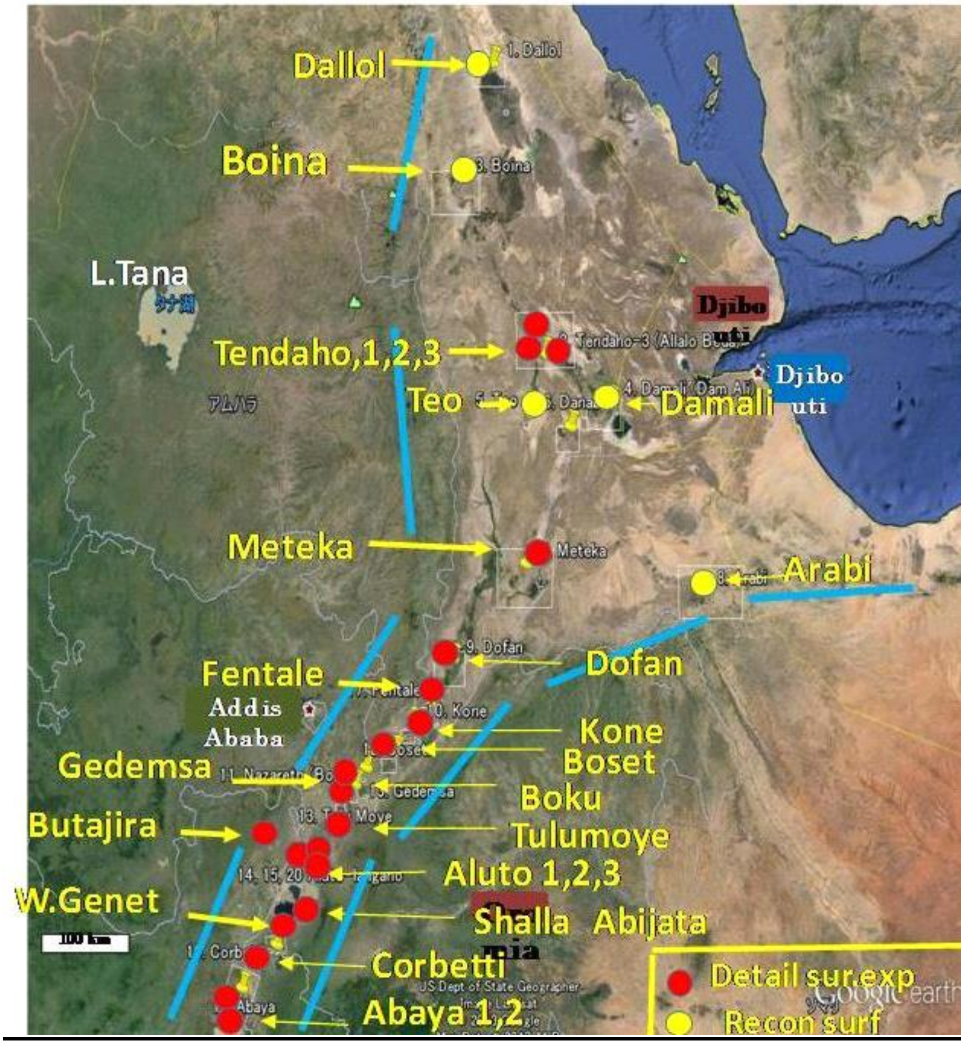

Figure 3: Location map of geothermal prospects in Ethiopia

(Fekadu, Kebede, & Kassa, 2022)

Detailed surface exploration has since been undertaken in about 16 sites and preliminary evaluation at six other sites (JICA, 2015). The prospects where detailed surface studies and/or drilling have been undertaken include Tendaho area in northern Afar (Ayrobera, Dubti and Alalobeda), those in central-southern Afar (Dofan, Fentale, Boseti, Boku, Kone and Meteka), and prospects in the southern rift (Aluto-Langano, Tulu Moye, Butajira, Shala-Abijata, Corbetti, Abaya, Wondo Genet, and Duguna Fango).

Geothermal fields and prospects

- **Dallol Geothermal prospect**

Dallol geothermal prospect is located in the Danakil depression, northern part of the Afar Region of the Ethiopian Rift Valley, 890km NE of Addis Ababa. It straddles the Ethiopia–Eritrea border, between the Ethiopian Plateau and the Danakil microplate in the northern part of the Afar Depression. The Afar Depression is an incipient seafloor spreading centre located at the triple junction between the Nubian, Somali and Arabian plates. The Danakil Depression, in the northern tectono-magmatic domains of the Afar Depression, is a well-defined tectonic entity, bordered to the west and east by major faults and dissected escarpments (Tesfaye, Harding, & Kusky, 2003). The main volcano-tectonic features of these magmatic segments are the NNW-SSE axial volcanic edifices and fissured basalts, open extensional fractures and vertical step faults. Volcanic activity in this region has been intense since the Pliocene, but is now mainly confined to the axial zone, with its spectacular shields and stratovolcanoes (Cavalazzi, et al., 2019). Limited geothermal exploration studies have been undertaken in the area and includes geological mapping, gravity and magnetic surveys. The hot springs at Dallol have very high salinity with chloride content of more than 366g/L; several times more than sea water. Additional studies are required to further confirm the presence and characteristics of the geothermal reservoir to allow for appropriate technology for utilization of energy from such high salinity fluids.

- **Boina Geothermal Prospect**

The Boina geothermal prospect (also known as Dabbahu) is located around 630 km east of Addis Ababa, in the remote Afar Region of Ethiopia. In the region, there is the stratovolcano Dabbahu (toping 1401m) which is part of the Afar Triangle (Afar Depression), a highly active volcanic region which includes the Erta Ale. The tallest point in the region is Mount Dabbahu, 1.401 m. Dabbahu volcano developed in this transitional zone, notably on a well-expressed transverse fracture at the junction (transverse structure) between Alayta and Manda Harraro axial ranges. The Dabbahu volcano is characterized by a magmatic series ranging from basalts to hyperalkaline rhyolites (comendites and pantellerites), emitted through N-S fissures associated with the two-major axial (NNW-SSE) ranges of Alayta and Manda Harraro. The more recent eruption of Dabbahu volcano dates back to 2005. The crystalline fractionation of this magma indicates the presence of a shallow magma chamber (Gardo and Varet, 2018). The geothermal manifestations are hot springs, fumaroles, and silica deposits. These fumaroles are locally called Boina, which means fumaroles or steam vents in the Afar language. Only limited geophysical surveys have been undertaken in the area suggesting possible existence of a high temperature geothermal reservoir.

- **Tendaho-Dubti Geothermal field**

Initial exploration of the Tendaho geothermal field took place in the 1970s and 1980s which culminated in the drilling of exploration wells at the sector known as Dubti (Tendaho-1) (Figure 66) between 1993 and 1998. Three three deep wells (approximately, 2,100 meters) and three shallow exploratory wells (approximately, 500 meters) were drilled in the field and intersected reservoirs at temperatures of more than 250°C (Megersa & Getaneh, 2006). The drilling work in this geothermal field was jointly funded by the Italian and Ethiopian governments. Preliminary production tests have shown that the shallow reservoir at Dubti can generate approximately 25 MW while the total generation capacity of the entire Tendaho including all the sectors is estimated at over 1,000 MW (Fekadu, Kebede, & Kassa, 2022). The other prospects within Tendaho graben are Ayrobera and Alalobeda (Figure 6).

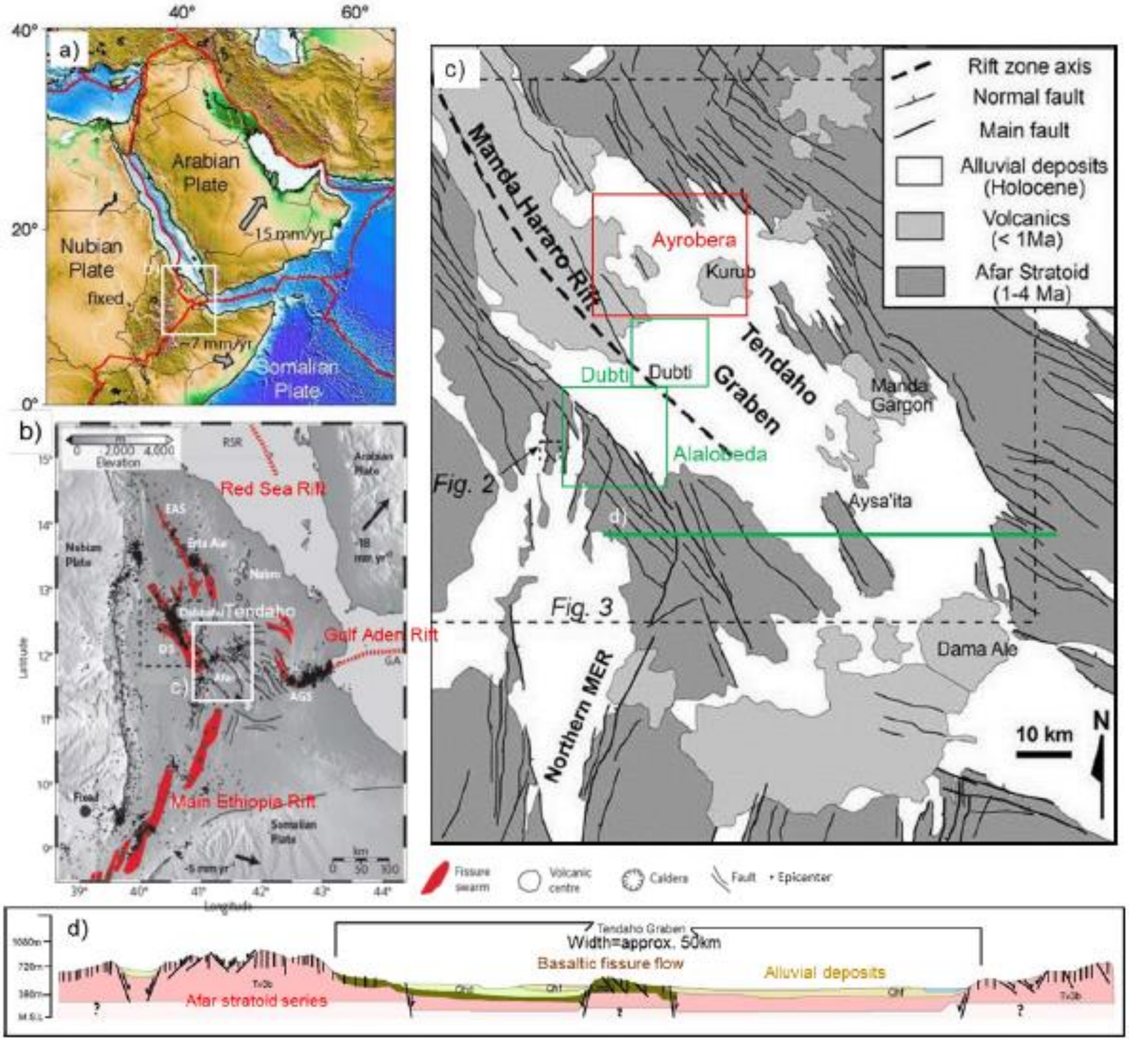

Figure 6: Structural map of the Tendaho Geothermal field in Afar depression

- **Alalobeda Geothermal Prospect**

The Alalobeda geothermal prospect is characterized by the presence of basaltic rocks of the Afar Stratoid series of Upper Pliocene to Lower Pleistocene age. The area is highly faulted with two dominant trend: NNE-SSW and NW-SE systems. Another set of faults trend in the WSW-ENE direction (JICA, 2015); (ELC Electroconsult, 2015). Detailed surface exploration was completed in 2015 and indicated the presence of a high temperature, liquid dominated geothermal reservoir with temperature of more than 200-220°C (ELC, 2016). The studies reveal possible potential of about 125 MW (ELC - Electroconsult, 2016). Therefore, four deep test wells are planned to be drilled with the support of the World Bank and JICA.

- **Ayrobera Geothermal Prospect**

The Ayrobera Geothermal Prospect is located in the east part of Tendaho Graben (Figure 66). It's located to the NE of the Dubti geothermal field. Geologically, the Ayrobera geothermal area is covered by basalt, rhyolite, and sedimentary deposits. This basaltic rock, which interbedded with the sedimentary layer, was formed as a result of volcanic activity during the spreading process of the Tendaho graben. The NW-SE oriented fissures developed in this area are concentrated in the centre of the Ayrobera zone. Detailed surface studies resulted in the siting of three exploration wells that will be drilled by EEP with the support of the World Bank (Cherkose & Saibi, 2021).

- **Teo Geothermal prospect**

Teo geothermal prospect is located NE of Meteka prospect. It is in the Southern Afar Region, of the Ethiopian Rift Valley and lies about 460 km NE of the capital, Addis Ababa. This area is flat lying horizontal plateau type at an elevation of between 500 and 600 m. The zone features a succession of N-S oriented faults which have produced horst and graben structures. The geology of the area is dominated by the Afar stratoid basalt series. The strata bound series were formed by the superposition of basic lava flow and associated scoriaceous layers. The area was then affected by intense N-S and NW-SE trending faults. There are no central volcanoes in the prospect. Manifestations occur in the form of hot springs with temperatures between 62 and 97°C. Fluid geothermometry suggests reservoir temperatures of more than 165°C. It is most likely that the resource is associated with deep circulation, fault controlled geothermal system. The prospect is remote and therefore development priority is low (JICA, 2015).

- **Danab Geothermal prospect**

Danab geothermal prospect is located in the central Afar Region of the Ethiopian Rift Valley, about 450 km NE of the capital, Addis Ababa and 20km to the south of the Ethiopia-Djibouti border. This geothermal prospect is bounded to the north by the Kakle graben that trends generally N-S. The formation is deeply faulted with downthrows of more than 200m thickness. Another minor E-W tectonic trend has been observed in the area. This trend is represented by faults with limited vertical movement, while just to the north, the tectonics formed the Dulul and Lake Abhe grabens. The escarpments of the main grabens are generally characterized by alluvial fans and talus slopes formed of basaltic gravels, while the lower parts of the depressions are filled with clays, silts and alluvial sands. Geothermal manifestations are hot springs with temperatures ranging from 86 to 95°C. Geothermometry estimates reservoir temperatures of 175-180°C (JICA, 2015). The geothermal model is deep circulation fault-controlled system.

- **Meteka Geothermal prospect**

The Meteka geothermal prospect is located in the transition zone between the Ethiopian and Afar rifts. The Meteka area is located NE of Dofan volcano within the Southern Afar Region of the Ethiopian Rift Valley, 350 km NE of Addis Ababa. This area is characterized by the presence of two caldera volcanoes: Abida and Ayelu. The two volcanoes produced lava flows of intermediate rhyolitic to peralkaline composition. Hot springs occur in the area with discharge temperatures of between 85-90°C. Geothermometry suggests low temperature reservoir of 125°C.

- **Hamokale Geothermal prospect**

Hamokale geothermal prospect is located in the southern Afar Depression along the foothills of the ENE-WSW trending escarpments of the south-eastern plateau and extends a distance of more than 85 km. The main lithostratigraphic units exposed in the vicinity of the Arabi and Armukalea geothermal sites include Precambrian crystalline basement, Mesozoic sediments, pre-rift Tertiary basalts, Afar stratoid basalts, fluvio-lacustrine sediments, and Quaternary volcanic rocks (Tefera et al., 1996). In the Erer area, the lithostratigraphic units consist of Mesozoic sediments exposed along the ENE-WSW-trending faults. The lower plains are covered by fluvio-lacustrine sediments consisting of calcareous and gypsiferous silts and sands with colluvial gravels and sands. These sediments are interspersed with scoraceous basalt along the Bowna stream, a tributary of the Erer stream. In the Armukalea-Artu geothermal site, altered basalts of the Alajae formation outcrop along the bed and banks of the Amare-Arjea shet. SW of the river and town, Quaternary volcanic activity is represented by the Isasor volcanic domes. The geothermal activity is linked to these Quaternary rhyolitic volcanoes. In the Arabi geothermal site, basaltic lava flows represent Quaternary volcanic activity. Geothermometry reveals the reservoir estimate above 250°C for the Arabi geothermal site; and 120°C for the Erer geothermal prospect (Geological Survey of Ethiopia, 2012). The government has issued a reconnaissance license to a private developer who has prepared detailed plans for project development.

- **Dofan Geothermal Prospect**

Dofan area is located in the Southern Afar Region of the central part of the Ethiopian Rift Valley, about 200 km NE of Addis Ababa. The geology is defined by the presence of the Dofan volcano and NNE-SSE oriented fault system. The magma type is dominated by silicic - mugearitic to supersaturated trachytic to peralkaline rhyolitic compositions. The second period is the formation of the Dofan volcanic edifice. The Dofan volcano is faulted and has a graben structure in its central part, which trends NNE-SSW. No drilling has been undertaken in the area but the resource has been modelled as high temperature, magma driven heat source with geothermometric estimates of 200-280^{o}C.

- **Fantale Geothermal Prospect**

Fantale geothermal prospect is located in the Southern Afar Region of Ethiopian Rift Valley, about 160 km NE of the capital, Addis Ababa. The geology is dominated by the occurrence of the Fantale caldera volcano that last erupted in 1820CE. The caldera has an elliptical shape with the main axis is oriented WNW-ESE. In the eastern part of Fantale, there are products of an old, dissected volcano called Tinish Fantal of silicic to intermediate composition. The caldera has a resurgent dome in the centre consisting of numerous trachytic lava-flows and pantelleritic obsidian flows. Detailed reconnaissance studies reveal that the geothermal system is of magmatic type with the heat source directly underlying the volcano. Detailed surface studies are planned in the near future.

- **Kone Geothermal prospect**

Kone geothermal prospect is one of the largest volcanic centres in the northern Main Ethiopian Rift (MER). Kone caldera forms part of a system of nested caldera within the older and larger Birenti Caldera. There is also the smaller Korke caldera. All the calderas are nested and collapsed at different times. The main caldera is cut by numerous faults with escarpments (up to 200 m high), some of which trend north and others west. It is anticipated that there could be possibility for a magmatic heat source. Permeability is expected to be high due to the intersecting faults and caldera collapse features. Recharge for the system is thought to be poor due to the geological structures that may form hydrological barriers. It is anticipated that a viable geothermal system driven by a magmatic heat exists in the area (Abera, Abebe, & Birbersa, 2019). Detailed surface studies are planned in the near future.

- **Boseti Geothermal Prospect**

The Boseti geothermal site is located about 90 km away southwest of Addis Ababa in Oromia Region centre of Ethiopia and is located in nearly the centre of Ethiopia Rift Valley which developed along NE-SW direction. Boseti Mountains comprises the peak of Bericha Mountain in the north and Gudda volcanic Mountain in the south. Boseti-Gudda and Boseti-Bericha are composed dominantly rhyolitic-to-trachytic volcanics. The volcanic complex is dominated by basaltic-to-trachytic suite which was followed by rhyolitic effusive and explosive eruptions that resulted in the caldera caldera. Post-caldera activity comprises recent pantelleritic obsidian fissure-fed lava domes and flows that buried part of the caldera wall. Flank eruptions from fissures parallel to the rift produced voluminous pantelleritic lava flows. Bericha has produced similar very recent obsidian flows and associated pumice flows. Fissures connecting Boseti and Bericha have erupted youthful, prehistorical basaltic lava flows. Detailed surface studies including MT/TEM, geology and geochemistry were undertaken by JICA (JICA, 2015). The studies revealed geothermometric temperature estimates of more than 210-260°C and was therefore prioritized for exploratory drilling.

- **Boku Geothermal prospect**

The Boku volcanic complex is an early Quaternary large caldera volcanic complex situated in the axial segment of the Main Ethiopian Rift (MER), located 92 km South-East from Addis Ababa. The Boku central volcano lies within the axial zone of the Central Ethiopian Rift near the town of Adama (Nazareth). The Boku complex is characterized by two main phases of activity: pre-caldera/caldera forming eruptive activity and post-caldera eruptive activity. The volcanic stratigraphy consists from bottom to top of a sequence of rhyolitic lava flows, pumice flows, welded ignimbrite, pumice fall, rhyolitic lava dome, obsidian flow, lower basaltic lava flow, ash flow, basaltic scoria and upper basaltic lava flows. The rhyolites are the youngest volcanic products in the area. Geothermal manifestations occur in the form of fumaroles on the western slopes of the old caldera and which has been faulted and micro-grabens formed. Detailed studies have not been undertaken to fully characterize the geothermal system. It is suspected that the resource could be fracture controlled medium temperature resource.

- **Gedemsa Geothermal prospect**

Gedemsa is located east of Koka Lake (dam) in Oromia Regional State, about 100km from Addis Ababa city. The prospect area covers the Gedemsa caldera and the NE part of the Wonji Sugar plantation. The caldera is almost complete but is cut by numerous NNE trending faults and some few resurgent silicic domes on the caldera floor. Open faults cut through the caldera on the eastern side. Studies suggest that the caldera was formed several explosive eruptions (Giordano, et al., 2014). Preliminary studies undertaken do not clearly show the presence of a geothermal system (Abera, Dander, Mengste, Burusa, & Beyene, 2014). There are also no geothermal manifestations reported in the area and thermal gradient holes (TGH) drilled within the prospect did not encounter thermal anomalies up to the drilled depths of 100m. Further studies are required to evaluate the presence of a geothermal system in the prospect.

- **Tulu Moye Geothermal Field**

The Tulu Moye geothermal field is located within the Main Ethiopian Rift system, some 100 km south east of Addis Ababa. The geothermal field is located north of Lake Ziway, offset to the eastern rift margin. The concession is licensed to Tulu Moye Geothermal Operations, Inc. The project has been undertaking exploration drilling since 2019 in the area around Tulu Moye volcano and along the Salen Range. The Tulu Moye geothermal field lies within a set of successive calderas of recent Quaternary age, covering a surface area of several hundred kilometres wide, crossed through by one of the active segments of the Wonji Fault Belt trending NNE-SSW known as Salen Range (Figure5). The area has transverse NW-SE magmatic and thermally emissive faults. Complete sets of differentiated magmas of fairly recent age (the last emitted circa two centuries ago), ranging from transitional basalts to peralkaline rhyolites suggest the presence of a heat source confirmed by geo-electric models. Six exploration wells have been drilled near Tulu Moye volcano in the SE of the prospect; western side and NW along the Salen Range. The first well drilled in the Tulu Moye geothermal field proved the existence of a high enthalpy geothermal system. The well produces steam of 1.5 MWe. The other wells drilled in the field showed that most of the areas drilled have low permeability and low reservoir temperatures. Additional appraisal and exploration wells are planned to locate the main upflow region.

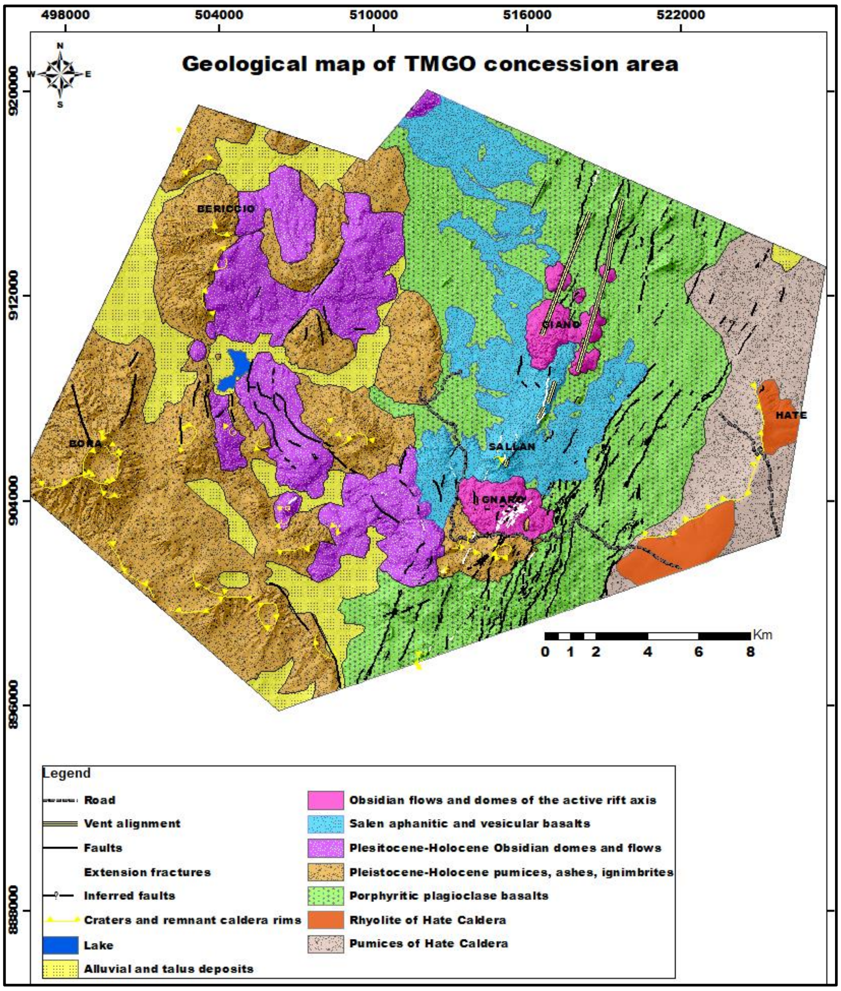

Figure 5: Geological map of the Tulu Moye geothermal field within MER

- **Aluto-Langano Geothermal field**

The Aluto- Langano geothermal field is the most developed geothermal site in Ethiopia. Detailed exploration surveys were carried out in the late 1970s to early 1980s which culminated in the drilling of eight exploratory wells of which four were productive. Following these results, an 8.5 MW (7.3 MW net) pilot plant was developed and commissioned in 1998. The plant uses combined cycle technology and operated from 1998 to 2001. However, between 2002 and 2007, the plant encountered operational challenges (Melaku & Thomasson, 2010), (IEA, 2019). The plant was repaired and partially operated from 2008 to 2011 before going out of operation again. The plant was again repaired and operated between 2013 to 2016 when its operation stopped to date. The Greater Aluto-Langano field has three target areas called Aluto Finkilo, Bobessa, and Adonsha (Figure 4). In Aluto Finkilo, thirteen wells have been drilled in the field and high temperature reservoirs encountered of more than 300°C. The latest wells were drilled between 2013 and currently in 2023. Wells LA-9D and LA-10D drilled in 2013 – 2014 have total production of about 5MW. A 5MW wellhead turbine has been constructed and due for commissioning in 2023 (Fekadu, Kebede, & Kassa, 2022). Reservoir simulations using data from the newly drilled wells and other previously drilled ones have shown that Aluto Finkilo has the potential to generate up to 35 MWe with financial support from JICA, the World Bank, the Scaling Up Renewable Energy for low Income Countries Programme (SREP), the Government of Ethiopia, and Ethiopian Electricity (EEP).

Bobessa is the eastern sector of the Aluto-Langano geothermal field (Figure 44). The studies indicate that the Aluto geothermal anomaly occurs not only along a fault zone located along the current productive wells but also close to the eastern margin of Aluto caldera, known as Bobessa. The conceptual model developed for this area indicated a potential of 35 MWe (ELC, 2016). One well was drilled in 2021 but turned non-productive with a temperature inversion at depth. This prospect is targeted to produce 35 MW to result in the Aluto's combined generation capacity of 70MW by 2025. Additional exploration drilling is planned for after review of the conceptual model based on the results of the drilled well.

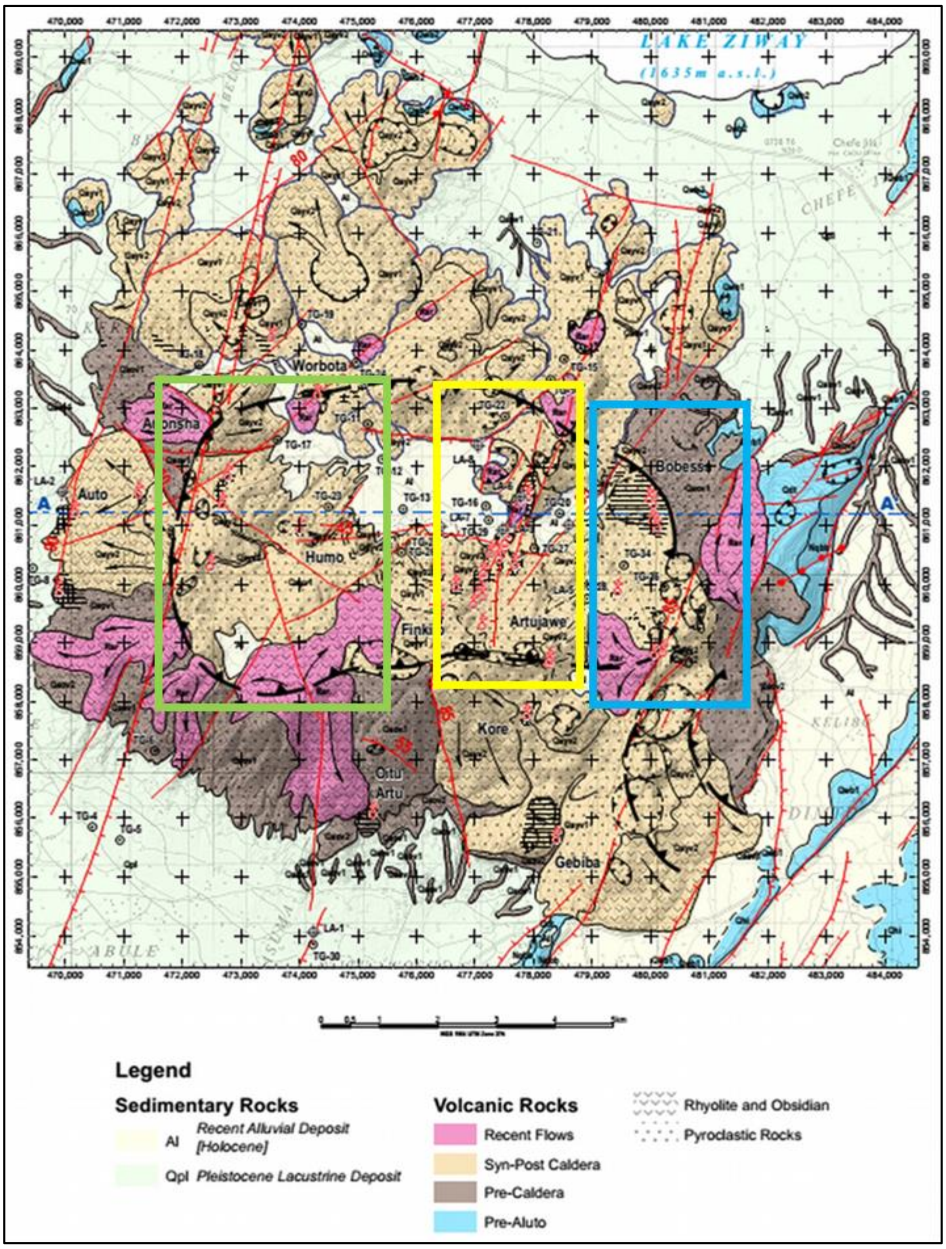

Figure 4: Geological map of the Aluto-Finkilo (Yellow), Bobessa (Blue) and Adonsha (Green)

Geothermal development status

There are two power plants that have been developed in Ethiopia: The 8.5 MW pilot plant commissioned in 1998 (Figure 77) and the 5 MW plant awaiting commissioning. The pilot power plant had a net power generation capacity of 7.3 MW (8.5 MW Gross). The plant used four of the eight wells that had been drilled at the Aluto field. The geothermal system at Aluto is of high temperature in excess of 300°C. The Aluto power plant is a combined cycle steam turbine with lower pressure bottoming steam turbine. Each of the turbines to deliver about 3.6 MW net. Several events, in particular corrosion, but also hydrothermal blockages, leakages, and lack of operation knowledge of the plant personnel led to several outages in power generation several times between 1998 and 2016 (Melaku & Thomasson, 2010).

Figure 7: Photo of the 8.5 Aluto Langano 8.5 MW pilot plant commissioned in 1998

EEP recently constructed a 5 MW Geothermal Wellhead Power System financed by JICA. The wellhead turbine and generator (GeoPortable Unit) were supplied by Toshiba ESS at a cost US$ 17 million. Construction and commissioning is expected in 2023 (Figure 88).

Figure 8: Aluto 5MW plant to be commissioned in 2023

- **Butajira Geothermal prospect**

Butajira geothermal prospect is located at the foot of western rift border fault about 150 km southeast of Addis Ababa in the low plains of the Ethiopian Rift. It is located at the base of the Zebidar massif in the Guraghe Zone of the Southern Nations, Nationalities and Peoples' Region. The Butajira and Debre Zeit Selti volcanic fields are located within the western margin of the MER and formally establish the off-axis belts of Quaternary activity. The latest volcanic episode (<3 Myr) is composed of uncompact pumice fall and flow deposits, rhyolitic–trachytic lava flows, and fissural basaltic lava flows interbedded lacustrine deposits. Several basaltic cones and some flows originate from the fault zones. Geological mapping and geophysical surveys undertaken in the area identified anomalies associated with fault zones. Fluid geochemistry suggests reservoir temperatures of 89 - 150^{o}C (Gebrewold & Belay, 2017). Because of the presence of Quaternary volcanoes within the prospect and 3He/4He ratio consistent with crustal contamination suggested presence of shallow magma bodies (Sinetebeb, Yirgua, & Barry, 2020). However, field relationships clearly indicate that the prospect is a fault controlled, deep circulation medium temperature resource.

- **Wondo Genet Geothermal prospect**

Wondo Genet area is located east of Hawassa town in the Sidama Regional state, about 280 km south of Addis Ababa. This is an off-rift geothermal system on the eastern fault escarpment, east of Lake Hawassa. The prospect does not have Quaternary volcanism. The volcanics present are of Pliocene age associated with early rifting events. The rock types in the area are trachytes and ignimbrites of Pliocene age. The area is heavily faulted and brecciated by both the young NNE trending faulting episode and the NW structures which formed heavy brecciation in the outcrops. The faulting events created steep and high slopes and faulted hill block. No detailed geophysical surveys have been undertaken in the area. Fluid geochemistry yielded a geothermometric temperature range of of 140-148 ºC (Beyene & Teklemariam, 2005). Based on geological setting, nature of heat source and fluid chemistry, it is proposed that the Wondo Genet is a low to medium temperature geothermal system developed through deep circulation along the rift faults. Currently, a popular hot bath/spa is located at the main hot spring and serves the local community.

- **Duguna Fango Geothermal prospect**

Duguna Fango is located in the Southern Nations, Nationalities, and Peoples' Region of Ethiopia north of Lake Abaya and south west of Lake Hawassa and about 330 km from Addis Ababa. The prospect lies to the north of the Abaya geothermal prospect. The prospect is centred on the Duguna Fango volcanic centre which is the most prominent central volcanic centre in the area. The volcano is likely of late Pliocene or early Quaternary age as the top part has thick soil which is heavily cultivated. There are no geothermal manifestations within the caldera floor and on the slopes of the mountain. Manifestations within the prospect occur along River Bilate on the plains adjacent to the volcanic edifice. It is most likely that these hot springs are not related to the Duguna Fango volcano but are fault controlled deep circulation systems on the rift floor.

- **Corbetti Geothermal prospect**

Corbetti is located north of Hawassa Town within the Main Ethiopian Rift in central Ethiopia, within Oromia Regional State. Corbetti is a large caldera volcano with resurgent activities at Chabbi, Urji and Artu volcanoes. These volcanoes erupted mainly rhyolitic lavas, obsidian and pyroclastics. Geophysical studies imaged anomalies that have been interpreted to indicate presence of geothermal reservoirs. The project is planned for 500MW to be implemented in phases starting with 50MW. Drilling of the exploration wells was planned to commence in 2023. The area has a large population, good road access, and is located near the national grid. The second phase will include the construction of additional geothermal wells and a 100 MW power plant and facilities. This is the second private investment concession in Ethiopia with PPA and implementation agreements signed for geothermal development in Ethiopia after Tulu Moye geothermal project.

- **Abaya Geothermal Prospect**

Abaya geothermal prospect is located north Lake Abaya and south of Duguna Fango volcano, within the Southern Nations, Nationalities and Peoples' Regional State (SNNPR) about 280 km southwest of

Addis Ababa. The site is located within the axis of the rift with local geology dominated by igneous and sedimentary rocks. On the rift floor occurs Tertiary ignimbrites, of the the Chewkare formation, which are exposed especially in the area to the northwest of Abaya (Chernet, 2011). The ignimbrite is overlain by lava flows originating from the many felsic eruptive centres present in the area. Alluvial and fluvial sedimentary deposits are of Pleistocene – Holocene age. The last stage of the volcano – tectonic activity took place during Pleistocene to present in the MER and is related to the axial extensional zone tectonics of Wonji Fault Belt (WFB), which produced bimodal basalts and rhyolitic products on the rift floor (Chernet, 2011). However, there are no young Quaternary central volcanoes within the license area. Geothermal investigations undertaken include geophysics, geology and geochemistry. Resistivity anomalies suggest presence of a clay cap overlying a high temperature geothermal reservoir but the anomalies are not well resolved. Fluid geochemistry shows geothermometry of more than 200°C for some hot springs but majority of the hot springs suggest medium temperature geothermal systems. The nature and geological characteristics of the prospect suggests that the geothermal system could be a result of deep circulation through the rift floor faults. It is therefore, recommended that the conceptual model should be re-evaluated in details to establish the controls on the geothermal system in the area.

Direct Use applications

Ethiopia has a history of utilizing geothermal resources dating to about 1880 when it was used mainly for bathing by the royalty. These hot springs are still in use today with a bathing facility open to the public at Filowha in Addis Ababa. Further recorded utilization is at the National Palace hotels (Ghion, Sheraton and Hilton) and some schools (Beyene & Teklemariam, 2005). Hot bath is highly revered in Ethiopia and therefore nearly all hot spring sites have been developed for some commercial scale use. These include sites in Butajira, Wondo Genet, among others. In spite of the low level of utilization, the country has large potential for direct use for industrial applications, green house heating, bathing and aquaculture, among others. 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 development of these resources by communities, regional governments, and private sector (Government of Ethiopia, 2016). The Climate Technology Centre & Network (CTCN) singled out Aluto-Langano (Oromia state), Dubti (Afar State), and Abaya (Southern Nations Nationality People Regional State) as areas where geothermal direct utilization would bring many economic benefits (CTCN, 2020). Suggested applications include fish drying, greenhouses and balneotherapy applications. JICA survey also suggested fish drying as a potential application of geothermal heat direct utilization at some of the prospects (JICA, 2015). Ambo hot spring is one of the few developed geothermal tourist destinations in Oromia. The Ambo hot springs area has bath, swimming and bottling of mineral water.

Policy, regulatory and institutional framework for development of geothermal resources

Institutional framework

The geothermal sector activities in Ethiopia are managed by the Ministry of Mines and the Ministry of Water and Energy (Figure 9). Since the year 2013, the government of Ethiopia has allowed active entry of private sector players for reconnaissance, exploration and development of both high temperature and low temperature resource for electricity generation and direct uses. The government Ministries and agencies responsible and described below:

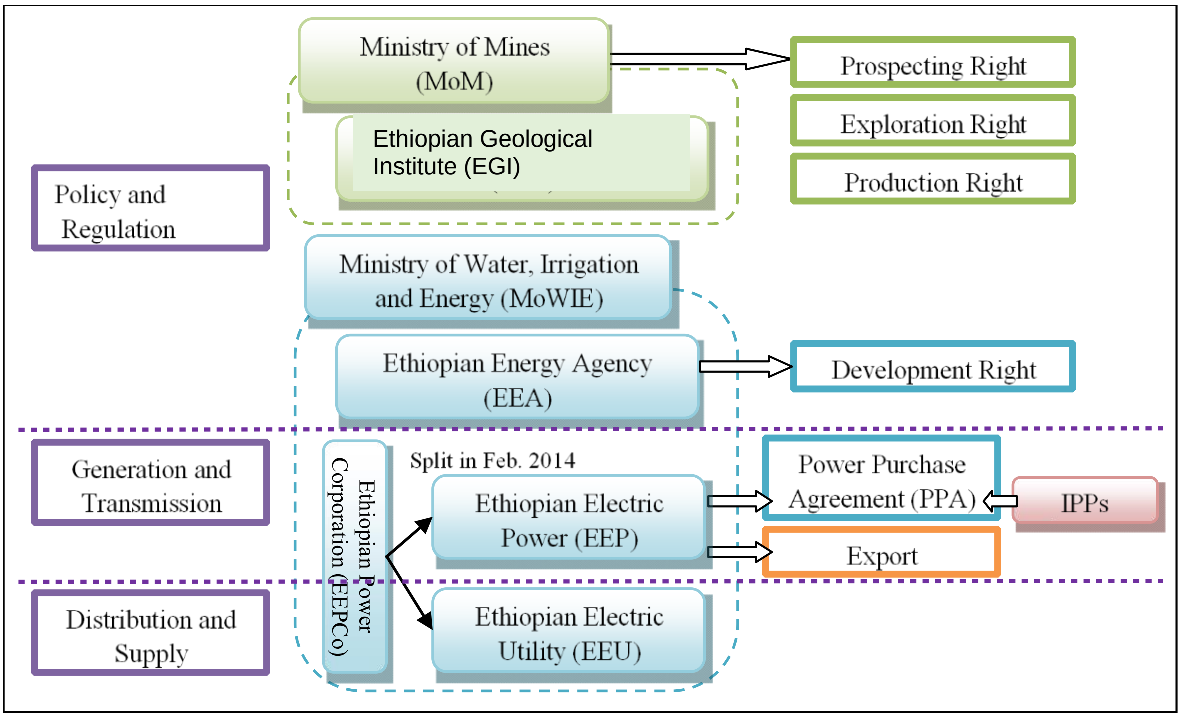

Figure 9: Ethiopia Institutional Setup Diagram

- **Ministry of Mines**

The Ministry of Mines (MoM) is the ministry responsible for policy and license management for geothermal, mineral resources, and petroleum development in Ethiopia. The ministry is tasked to promote the entry of private investors into the business in these sectors, MoM provides the most up-to-date geodata and guidance for the right legislation and regulations (Ministry of Mines, 2022).

- **The Ministry of Water, Irrigation and Energy (MoWIE)**

The Ministry of Water, Irrigation and Energy (MoWIE) is the main ministerial body in charge of energy policy and execution. It ensures the development of energy generation, transmission and distribution. MoWIE plans, leads, co-ordinates, and monitors Ethiopia's overall energy strategy and development. It is also the supervising authority for the Ethiopian Energy Agency (EEA), Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). Within the ministry there are various directorates tasked with policy drafting, implementation follow up and supervision. These directorates are also charged with conducting research and studies that including the development and promotion of rural energy efficient technologies such as improved stoves solar and bagasse. The directorates are also responsible for setting standards for biofuel and petroleum oil products, depots and retail facilities. These directorates include energy studies & development follow-up, hydropower and dams administration, bio-fuel development coordination, petroleum downstream operation regulation and alternative energy technologies promotion & dissemination (Ethiopian Electric Poweer, 2014), (Ministry of Water and Energy, 2012).

- **Ministry of Finance**

Funding from the Ethiopian government will be provided through the Ministry of Finance, and the ministry is the Ethiopian counterpart in receiving financial support from international institutions. The Ministry is the sole shareholder of the EEP and EEU on behalf of the Government.

- **Ethiopian Electric Power (EEP)**

EEP is the national power company of Ethiopia. It is engaged in the construction, operation, and management of power plants and transmission networks, and wholesale of electricity to the distributor. EEP owns and operates all high voltage transmission lines above 132 kV, including all attached substations. Ethiopia has also allowed independent power producers to build and operate power plants to supply electricity to the national power grid since 2017, but currently EEP owns and operates nearly all power plants in the national power grid. The company owns 18 power plants, and a total generating capacity is 5,275 MW. The 18 plants include 14 hydropower plants (4,818 MW), 2 wind power plants (324 MW), and 1 geothermal plant (8.5 MW, non-operational). The remaining 100 MW electricity is from diesel generators (Ethiopian Electric Power, 2023). The total length of high-voltage transmission lines has reached more than 17,000 km across the country ranging from 132 V to 500kV. EEP provides electricity to the large industries and neighbouring countries, such as Sudan, Djibouti and Kenya.

- **Ethiopian Electric Utility**

EEU is a national power company of Ethiopia engaged in the construction, operation, and management of off-grid power plants (up to 5MWe); low-voltage-level transmission networks (up to 66kV) and sale of electricity to consumers (Ethiopia Electricity Utility, 2022).

- **Ethiopian Energy Authority**

The EEA is the key regulator of the energy sector in Ethiopia and is accountable to MoWIE. EEA is established under the Energy Proclamation No. 810/2013 to regulate and provides rules for the generation, transmission, distribution and sale, importation, or exportation of electricity. EEA may grant the geothermal operation licenses (reconnaissance, exploration, well-field development, and use) on Grade I geothermal resources (a type of geothermal resources capable to generate electric power and to provide services, such as direct heating and combined heat and power) (Government of Ethiopia, 2016). The EEA mandate as it relates to geothermal development is to promote competitiveness in the energy sector through effective implementation of the Energy Proclamation, Energy Regulation, Investment Proclamation, Geothermal Proclamation and Geothermal Regulation.

- **Ethiopia Geological Institute**

The Ethiopian Geological Institute (EGI) is an autonomous institution, with accountability to the Ministry of Mines (MoM) and was formerly known as Geological Survey of Ethiopia (GSE). EGI is responsible for carrying out basic geological mapping, geothermal exploration, mineral exploration, and related geological activities. They also provide services, such as data dissemination and drilling and laboratory analysis.

- **Ethiopia Regional States**

Regional States (nine regional states and two cities in the country) have been granted authority to issue operation licenses on Grade II geothermal resource (direct use for the purposes, such as direct heating, agricultural and industrial applications, and recreational bathing and medicinal purposes), where the temperatures do not exceed 120°C and volume not exceeding 2,000,000 m^3/year (Government of Ethiopia, 2016).

- **Environment, Forest, and Climate Change Commission (EFCCC)**

EFCCC, formerly the Environmental Protection Agency, is the Federal institution managing Ethiopia's environment. It is an independent authority, acting outside the main ministerial structures and reporting directly to the Prime Minister. EFCCC has delegated to MoM the responsibility for environmental and social impact assessments review, monitoring and compliance for large-scale projects, and to regional bureaus for any projects that fall under the jurisdiction of regional states (Ministry of Mines, 2022).

Policy and regulatory framework

- **National Energy Policy**

The National Energy Policy aims to promote the development of the energy sector in a manner coordinated with the overall economic development of the country. The policy focuses on increasing access to electricity, improving security of supply, addressing the financial capacity of sector institutions, promoting energy efficiency and conservation, encouraging the development of renewable energy, setting commercial prices for energy resources, promoting electricity exports, improving reliability and service quality, and introducing technical and commercial service standards (Government of Ethiopia, 2014).

- **Geothermal Resources Development Proclamation No. 981/2016 and Geothermal Resources Development Council Minister of Regulation No. 453/2019.**

These acts define geothermal development in Ethiopia. These acts define terms and general provisions related to geothermal development (securing land for geothermal development and registration of geological resources), the establishment of EEA and its role, the types of geothermal development licenses and the requirements for obtaining them (three types of geothermal development licenses: reconnaissance license, exploration license and geothermal field development and use). To obtain a geothermal well development and use license, a work plan, feasibility study, and environmental impact assessment results must be submitted to EEA for approval, and a PPA must be concluded. At the end of the 25-year validity period, the license shall be transferred to the government. In addition, these acts also regulate compensation to the local community, and tax exemptions for project developments.

- **Regulation for Geothermal Power Plant License and Authority vide Energy proclamation No. 810/2013, (updated as No. 1085/2018)**

This proclamation regulates the energy generation and distribution market segments, containing provisions for the establishment of EEA and its powers and duties, licensing requirements, electricity supply activities and their use of land, energy efficiency and conservation, criminal penalties for crimes related to energy efficiency and licensing.

- **Regulation for Environmental Impact Assessment Proclamation No. 299/2002**

This proclamation outlines the environmental impact assessment (EIA) process required for project implementation and the relevant regulatory agencies. The environmental authorization of projects is delegated to five ministries, such as Mines and Petroleum, Water, Irrigation and Electricity, Agriculture and Livestock, Transport, and Construction. Any large projects or transregional projects in these sectors requiring EIA in Ethiopia, EIA process is conducted through these ministries. Each of these ministries will establish Environmental and Community Development Directorate to serve as the point of contact for EIA. In the case of large projects requiring EIAs in business sectors outside the jurisdiction of these ministries, such as industry and health, Environment, Forests and Climate Change Commission (EFCCC) serves as the administrative office for EIA. Any project which may require an EIA at the regional or local level, each regional state will apply for an Environmental Authorization through the regional state authorities. The regional state authority will issue an environmental authorization, and this will be submitted to the relevant ministry to be included in the overall operation license approval by the Ministry.

- **Public Private Partnership Proclamation No. 1076/2018**

This proclamation, together with the Supplementary Regulations issued by the Ministry of Finance, is the governing law for the procurement of public-private projects. This establishes the PPP under the Ministry as the competent authority overseeing public procurement procedures. This proclamation promotes competitive procurement as the preferred option for public procurement and streamlines the procurement procedure process and defines institutional responsibilities. PPP projects are prioritized by the Public-Private Partnership Committee. Prior to the enactment of this proclamation, the electricity market for private sector power generation investments was primarily through the submission of unsolicited procurements. This approach was time consuming, involved lengthy negotiations, increased uncertainty, and lacked confidence that financial markets would support such infrastructure development projects.