

Integrated Assessment of Challenges and Strategic Mitigation Approaches for Geothermal Energy Development in Ethiopia

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Abstract: Ethiopia has significant geothermal potential in the East African Rift System, but not much has been done to develop and utilize this resource despite exploration efforts starting in 1969. The primary barriers to Ethiopia's geothermal energy sector development are thoroughly examined in this paper, along with practical ways to get past them. Lack of skilled labor, inadequate institutional and policy frameworks, a lack of government support, high upfront exploration and drilling costs, technological and infrastructure gaps, and competition from more highly valued renewable energy sources particularly hydropower are some of the primary challenges mentioned. The Aluto-Langano pilot plant's poor performance, which damaged trust in geothermal investments, has also had a detrimental impact on the industry. On the other hand, Ethiopia has many advantages for expanding geothermal energy, such as abundant resources exceeding 10,000 MW, growing domestic demand for clean and dependable baseload energy, expanding international collaborations, and alignment with national energy diversification objectives. Based on lessons learned from successful geothermal economies like Kenya and Iceland, this paper proposes integrated mitigation strategies that include capacity building, policy and regulatory reforms, risk-sharing financing mechanisms, the establishment of an independent geothermal development agency, increased private sector participation, and strategic site prioritization. If properly implemented, these measures can accelerate geothermal development, attract sustainable investments, and assist Ethiopia in transitioning to a stable, low-carbon, and diverse energy mix. Ethiopia might become a regional leader in geothermal development and greatly increase its energy security with the use of geothermal energy.

Keywords: *Geothermal Energy Development, Barriers and Mitigation strategies, Sustainable Energy Policy.*

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I. INTRODUCTION

➤ Ethiopia Energy Sector

Ethiopia's energy sector is crucial to reaching its socioeconomic development and industrialization objectives. Ethiopia's economy, which is among the fastest-growing in Africa, has seen a sharp rise in energy demand due to factors like population expansion, urbanization, and infrastructural development. Although Ethiopia still faces challenges in meeting its electricity needs, it has a lot of promise for renewable energy(Woldie, 2025).

The country is endowed with an estimated renewable energy potential exceeding 60,000 MW, primarily from hydropower, wind, solar, and geothermal resources. Among these, hydropower represents the dominant source, contributing approximately 90% of the current installed electricity generation capacity, which stood at about 6,100 MW as of 2023. Wind and thermal sources make up the remainder, accounting for 8% and 2%, respectively. Despite

this capacity, access to electricity remains limited. It is estimated that only around 60% of Ethiopia's population has access to electricity, highlighting a considerable gap between supply and demand(Maagøe, 2023). This limited access is more pronounced in rural areas, where electrification rates are significantly lower compared to urban centers. The situation underscores the urgency of expanding generation capacity and diversifying energy sources to ensure reliable, affordable, and sustainable energy access nationwide.

Looking forward, the Ethiopian government has outlined an ambitious energy development strategy aimed at transforming the country into a regional power hub. This includes significant investments in expanding renewable energy generation and transmission infrastructure, with a particular focus on geothermal energy development. Ethiopia lies within the geologically active East African Rift System, offering substantial untapped geothermal resources estimated at over 10,000 MW. As hydropower becomes increasingly vulnerable to climate variability, geothermal

energy presents a reliable, baseload alternative that can enhance energy security and system resilience.

The development of the geothermal sector, however, faces several technical, financial, and institutional challenges. These include high upfront exploration costs,

limited local expertise, and regulatory uncertainties. Nevertheless, ongoing reforms in the energy sector support from international development partners, and increased private sector engagement present promising opportunities to scale up geothermal energy development in the coming years.

Table 1-The Table Below is Ethiopia Energy Sector Overview and Future Energy Development((GSE) Geological Survey of Ethiopia, 2015).

Source of Energy	Existing Capacity	Target Capacity for 2025 (MW)	Target Capacity for 2030 (MW)	On-Going Project (MW)	
				Under Construction	Under Preparation
Hydro power Energy	4820.3	10,817	20,200	8804	2280
Geothermal Energy	8.5	170	3,500	70	3009 (PPA & IA Signed)
Solar Energy	0	300	3,000	-	100(auctioned) 450(EOI)
Wind	324	1224	2,500	120	Multiple Project Preparation
Nuclear	0	0	2000	0	Under study
Waste Energy	25	0	300	-	-
Diesel	99.17	1,290	1,580	170	-
Total	5,275	14,208	33,080	9,164	3,130

➤ Ethiopia Energy Policy

As part of its larger objective to diversify the nation's primarily hydropower-based electricity mix and improve energy security, Ethiopia's national energy policy strategically emphasizes the development of geothermal energy (Addis Ababa, 2018). The policy recognizes the Ethiopian Rift Valley's vast geothermal potential estimated at more than 10,000 MW as a reliable, indigenous, and renewable baseload resource capable of complementing seasonal hydropower variability (Amanu et al., 2018). To realize this potential, the government prioritizes creating an enabling environment for exploration and investment through institutional reform, risk-mitigation mechanisms, and private sector participation via Independent Power Producer (IPP) frameworks. The policy underscores geothermal energy's role in supporting industrialization and rural electrification while contributing to climate resilience and reduced reliance on imported fossil fuels. Recent strategies, including the National Energy Policy (1994) and its subsequent updates under the Ministry of Water and Energy, as well as the Home-Grown Economic Reform and National Electrification Program, reinforce geothermal development as a key pillar of Ethiopia's sustainable energy transition. These frameworks aim to expand geothermal generation capacity through projects such as Aluto-Langano and Tulu Moye, supported by public-private partnerships and concessional finance. Collectively, these policy directions demonstrate Ethiopia's commitment to harnessing geothermal resources for long-term energy diversification, climate mitigation, and economic growth (MoWE, 2022) (Maagøe, 2023).

➤ Geothermal Development in Ethiopia

In 1969, the UNDP, the Geological Survey of Ethiopia, and the Italian geothermal company ELC began long-term geothermal exploration in Ethiopia (Kebede, 2023). "As evidenced by surface hydrothermal manifestations, a list of potential resource sites within the Ethiopian geothermal sector of the East African Rift system has been compiled over time" (Kebede, 2014c).

"The rift system has been thoroughly covered, but the inventory work in the country's highlands is still incomplete. About two dozen of the 120 locations in the rift system that are thought to have separate heating and circulation systems are thought to have the capacity to develop high enthalpy resources, including the ability to generate electricity. A far greater number can be developed for non-electricity generation uses, like space cooling and heating, mineral extraction, horticulture, animal breeding, aquaculture, agro-industry, health and recreation, and mineral water bottling" (Mamo, 2002).

"The prospects where detailed surface studies and/or drilling have been undertaken include Tendaho area in northern Afar (Ayrobera, Dubti and Allalobeda), 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)" (Geological Survey of Ethiopia; 2015).

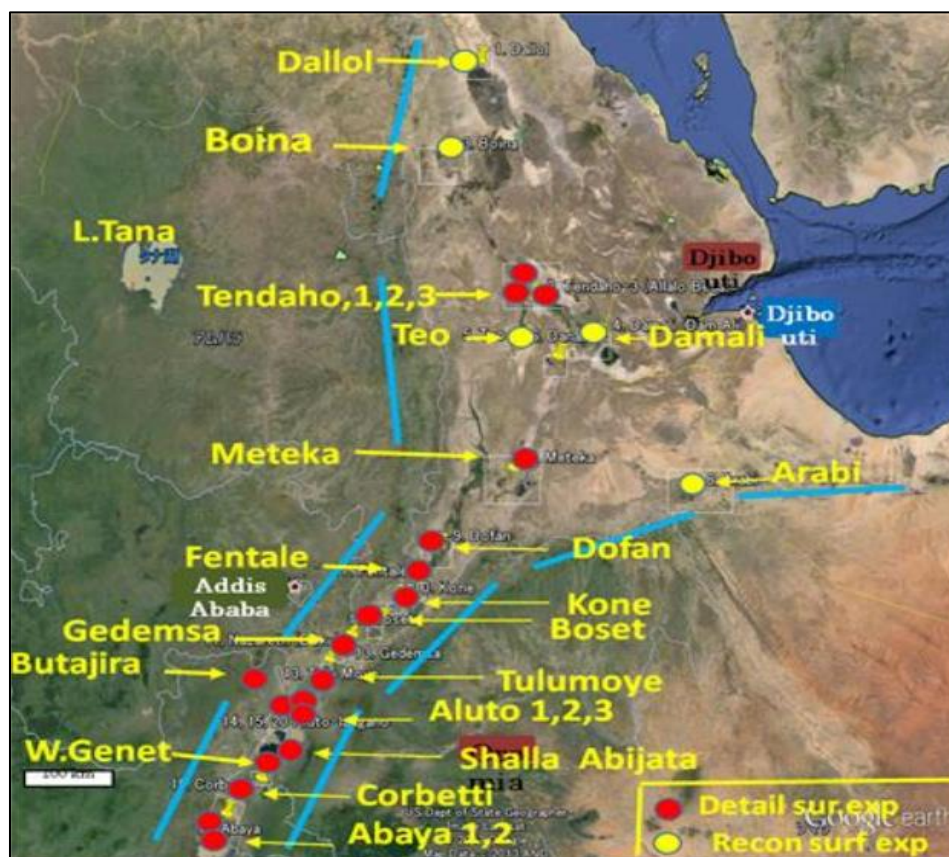


Fig 1-The Figure Above is “Location Map of Geothermal Prospects in Ethiopia”(Fekadu, 2014a).

II. OPPORTUNITIES OF GEOTHERMAL DEVELOPMENT IN ETHIOPIA

Geothermal resource potential in Ethiopia is estimated to be over 10,000 MW, making it a strategic opportunity to diversify the country's energy mix and promote sustainable development(Overview, 2021). The enabling environment for geothermal deployment has been further improved by strong government commitment, as evidenced by supportive policies, regulatory reforms, and investment incentives. Ethiopia also continues to gain from broad international cooperation with development partners like the World Bank, Icelandic International Development Agency (ICEIDA), Japan International Cooperation Agency (JICA), French Development Agency (AFD), and the United Nations Development Program (UNDP), which offer financial support, technical assistance, and capacity-building assistance(Kebede, 2014a)(Usui & Mohammed, 2016). Geothermal energy is becoming more and more important in the public and private sectors due to the rising demand for power and the need for dependable, low-carbon baseload generation. This further solidifies its position as a crucial component of Ethiopia's upcoming energy transition(Overview, 2021).

III. CHALLENGES OF GEOTHERMAL DEVELOPMENT IN ETHIOPIA

➤ Inadequate Human Power

In geothermal energy exploration, it needs adequate exploration abilities to identify and map out potential resources of geothermal energy. This lack of exploration can result in missed opportunities for resource development and economic growth(Kebede, 2014a). And also, geothermal well drilling needs special knowledge to mitigate different technical challenges which comes from complex geological formations, encountering high temperatures and pressures, etc. during drilling. Unless mitigations of these problems as soon as possible, the formation of the well will be damaged or encountering stacking of drilling string. And will be encountered hydrothermal eruption. Similarly, geothermal resource assessment needs adequate resource assessment abilities, which means that, the ability in the evaluation of the quantity, quality, and feasibility of extracting resources from a particular location. Without a comprehensive assessment, it is challenging to make informed decisions about the viability of resource extraction projects, leading to potential inefficiencies, wasted resources, and environmental impacts(Agency & Exploration, 2014). When we come to Ethiopia, as it known that, it has developed its geothermal capacity by working with expatriate experts and consultants. And also, geothermal work being done in Ethiopia is mainly with joint venture with external assistance and it was as per standard. Due to this, Ethiopia has exposed for lack of skilled human power. And also, some of the most

geothermal experts have leaved from geothermal sector due to retired and lack of salary.

➤ *The Abundance of Other Alternative Renewable Energy Resources*

Ethiopia's substantial endowment of hydropower, wind, and solar resources has likely influenced the prioritization of these alternative renewable energy sources over geothermal energy, particularly during the country's initial stages of renewable development. This emphasis on widely available and more mature technologies may have drawn greater attention and investment, consequently leading to comparatively less focus on advancing geothermal energy. Integrating geothermal power plants into an electricity grid predominantly supplied by hydropower presents notable technical and operational challenges, which could have further impeded the expansion of geothermal capacity. The existing grid infrastructure and management practices optimized for hydropower may not align seamlessly with the characteristics of geothermal generation, resulting in complexities that slow geothermal integration. Additionally, the presence of multiple viable renewable options has likely shaped resource allocation and investment decisions, with public and private stakeholders directing a larger share of financial and infrastructural support toward hydropower, wind, and solar projects. This distribution of resources may have inhibited the rapid scaling of geothermal initiatives. Furthermore, the concentrated development of hydropower, wind, and solar technologies may have limited efforts to cultivate the specialized technological expertise and skilled workforce necessary for effective geothermal exploration, development, and operation. Consequently, the relatively lesser prioritization and investment in geothermal energy not only reflect immediate economic and infrastructural considerations but also underscore the need to strengthen national capabilities tailored to geothermal technology to accelerate its contribution to Ethiopia's renewable energy portfolio(Overview, (2021); Ethiopian Energy Outlook, (2025); (Kebede, 2014b)).

➤ *Lack of Independent Organizational Structure*

The development of an independent organizational structure for Ethiopia's geothermal sector has been constrained by multiple interrelated factors. One primary challenge is the limited government support manifested through an unclear and insufficient policy framework, which lacks the supportive regulations and incentives necessary to foster geothermal development and institutional autonomy (Kebede, 2014b). This policy deficit hinders the sector's ability to establish a dedicated and empowered organizational body. Compounding this issue are significant financing and investment barriers; both public and private funding sources often fall short of providing the scale of capital required to build robust geothermal infrastructure and organizational capacity. Moreover, technical and technological limitations, including a shortage of skilled professionals, gaps in advanced geothermal technology, and inadequate physical infrastructure, collectively weaken the sector's foundation for independent institutional growth. The absence of a coordinated and centralized strategic approach further fragments the geothermal sector, generating

inefficiencies and a lack of cohesion that undermines the emergence of a unified organizational entity. This fragmented development is exacerbated by competing energy priorities within Ethiopia's energy landscape, where geothermal energy struggles to assert itself against more established and politically influential energy sectors such as hydropower, wind, and solar. These competing interests limit geothermal access to critical resources and autonomy, thereby impeding the establishment of an independent and effective organizational structure necessary for its sustainable development.

➤ *Other Challenges*

Ethiopia's geothermal energy sector faces multiple interconnected challenges that hinder its development and utilization. Technological and infrastructure limitations are significant barriers, as the sector is still nascent with a shortage of necessary expertise, drilling equipment, power generation technologies, and grid integration capacity. This technological gap constrains efficient exploitation of geothermal resources. Compounding these challenges is the unfavorable legacy of the Aluto-Langano pilot plant, Ethiopia's first and only geothermal power plant, which operated with combined cycle technology from 1998 to 2001. It ceased operation due to technical difficulties from 2002 to 2007 and despite repair attempts in 2008 and 2013, it could not resume operation, leading to governmental dissatisfaction and neglect of the geothermal sector(Impact et al., 2013).

High upfront capital costs pose another major obstacle. The exploration, drilling, and infrastructure costs for geothermal power plants are substantial, presenting a critical challenge in developing countries like Ethiopia, where access to initial capital investment is limited(Energy 101, 2017). Furthermore, the geothermal sector's inherent risks during early-stage development remain a concern. The sector's upstream activities, primarily within the public domain, such as resource exploration and confirmation, are planned to precede downstream development activities handled by the private sector, yet these arrangements face operational and investment uncertainties.

The scarcity of specialized equipment further complicates sector growth. Ethiopia lacks adequate drilling rigs and related instrumentation necessary for geothermal exploitation, with only two rigs available under Ethiopian Electric Power, underscoring the critical need for increased investment in capacity and technology acquisition. Additionally, environmental and social factors demand careful attention. The development of geothermal resources involves complex considerations including water use, land access rights, and community engagement, all of which must be managed to ensure sustainable and socially acceptable project implementation.

Together, these challenges reflect the multifaceted nature of geothermal development in Ethiopia, encompassing technological, financial, operational, and socio-environmental dimensions that require a coordinated

and well-supported strategy to progress the sector effectively.

IV. MITIGATION STRATEGIES FOR GEOTHERMAL ENERGY DEVELOPMENT CHALLENGES IN ETHIOPIA

➤ *Assessment and Analysis*

A comprehensive and data driven assessment and analysis is a critical precursor to accelerating Ethiopia's geothermal development. To achieve long-term energy security and sustainability, Ethiopia must first establish a clear understanding of the current state of geothermal resource management, drilling capabilities, institutional performance, and operational efficiency across all responsible organizations. These include, but are not limited to, the Geological Institute of Ethiopia (GIE), Ethiopian Electric Power (EEP), and other relevant stakeholders involved in exploration, drilling, project execution, and policy oversight.

➤ *Strategy Development*

To unlock the full potential of Ethiopia's geothermal resources and accelerate sustainable energy development, a comprehensive, phased, and results-driven strategy development framework is essential. This strategy must integrate clearly defined objectives, prioritized initiatives, actionable plans, and measurable milestones. It should be guided by national energy policy goals and aligned with Ethiopia's climate commitments, economic growth targets, and regional energy integration efforts under the East African Power Pool (EAPP).

➤ *Goal Setting*

Effective goal setting is a critical success factor in accelerating Ethiopia's geothermal development and ensuring strategic alignment across exploration, development, and institutional performance domains. To this end, clear, measurable, and time-bound goals must be defined across all core pillars of the geothermal value chain. These goals should be 'SMART' (Specific, Measurable, Achievable, Relevant and Time bound), and must be closely aligned with the national energy policy framework, the Geothermal Resource Development Master Plan, and Ethiopia's broader commitments to energy access, economic transformation, and climate resilience.

➤ *Policy and Regulatory Reforms*

The Ethiopian government should urgently develop a clear and comprehensive geothermal energy strategy and policy to guide sector growth and attract investment. It must prioritize extensive resource exploration and mapping to fully assess geothermal potential. Establishing dedicated funding and risk-sharing mechanisms is critical to overcome high initial costs and encourage project development. Promoting international partnerships will provide access to essential technologies and expertise, speeding up sector advancement. Strengthening technical and vocational training will build a skilled local workforce vital for sustainable operations. Finally, ensuring effective integration of geothermal power into the national grid is key

to maximizing its contribution to Ethiopia's energy mix and enhancing energy security. These coordinated actions are essential to unlock Ethiopia's geothermal potential and drive long-term, resilient energy development.

➤ *Financing*

Securing funding from both public and private sources, including international financing institutions, can help overcome financial constraints and support project scalability. Assess with foreign ministry and ministry of finance potential countries or institution who can assist technically, financially, under the framework of bilateral or multilateral cooperation. Then prepare viable project document, capacity building document etc. and share them for their consideration. Utilize blended finance methods and public-private partnerships to reduce the risk associated with geothermal investments.

Explore innovative financing instruments, such as green bonds or geothermal project bonds, to attract diverse sources of capital. Strengthen risk mitigation mechanisms, such as geothermal resource insurance or government backed guarantees, to reduce investor uncertainty. By adopting these strategies, innovative approaches, and technologies, Ethiopia can effectively harness its geothermal potential, attract investments, and establish a sustainable geothermal energy industry in the long term.

➤ *Creating Strong Independent Geothermal Development Organization*

Ethiopia should establish an independent geothermal development organization modeled after successful entities such as HS Orka in Iceland and the Geothermal Development Company (GDC) alongside Kenya Electricity Generating Company (KenGen) in Kenya. Creating a dedicated geothermal agency is vital to fully unlock Ethiopia's geothermal energy potential while integrating it effectively with other renewable sources like hydro, wind, and solar power. By fostering close collaboration between the Geological Institute of Ethiopia (GIE) and Ethiopia Electric Power (EEP), this specialized entity can lead geothermal development with significant advantages. It would assemble a focused team of experts and engineers dedicated exclusively to geothermal advancement, addressing the technical and capacity challenges currently limiting progress. Centralizing project management within this agency would streamline the development process, accelerating resource assessment, exploration, financing, regulatory approvals, and grid integration to ensure efficient and timely project delivery. Furthermore, as a specialized organization, it would be better equipped to attract both domestic and international funding, facilitating partnerships with foreign investors and technology providers essential for the sector's growth. This agency would also serve as a key liaison with the government to drive clear, supportive policy and regulatory frameworks, providing the foundation necessary for sustained geothermal energy development. Establishing such an organization is a strategic imperative for Ethiopia to accelerate its geothermal sector and realize its renewable energy ambitions comprehensively.

➤ *Establishing Good Enabling Environments for the Private Sector in Geothermal Development*

Creating a conducive environment for private sector participation is essential to attract investment, foster innovation, and accelerate growth in Ethiopia's geothermal energy sector. The government must establish clear, stable, and transparent policies and regulatory frameworks that ensure a level playing field and reduce investor risks by providing consistency and predictability. Encouraging public-private partnerships (PPPs) is critical to leverage the strengths of both sectors, share risks, and enhance project efficiency through effective communication and coordination mechanisms. Offering targeted fiscal incentives such as tax breaks, grants, loan guarantees, and investment risk insurance will increase investor confidence and stimulate private investment. The government should concentrate on completing upstream geothermal activities, from surface exploration to test well drilling, and then transfer projects to the private sector after mitigating initial risks. Streamlining permitting and licensing processes by creating a one-stop-shop regulatory body will reduce administrative burdens and expedite project approvals for private developers. Raising public awareness of geothermal benefits and actively engaging local communities and stakeholders in project planning is vital to building inclusivity, social acceptance, and addressing environmental concerns. Lastly, fostering market development through establishing off-take agreements, feed-in tariffs, and power purchase agreements will provide revenue certainty and stimulate demand for geothermal power, ensuring fair and supportive market conditions. These comprehensive measures are indispensable to unlocking private sector potential and driving sustainable geothermal development in Ethiopia.

➤ *Strategic Site Prioritization*

Not all geothermal sites possess the same potential, making it imperative to evaluate prospects using multiple comprehensive criteria to ensure efficient resource allocation and maximize Ethiopia's geothermal energy impact. Prioritizing sites with high resource potential such as those exhibiting high or low enthalpy, favorable temperature conditions, and sustainable reservoirs is essential for achieving long-term energy production. Additionally, technical feasibility must be assessed by considering site accessibility, drilling complexities, and existing infrastructure to ensure project viability. Environmental impact evaluation is critical to minimizing ecological disruption and promoting sustainable development practices. Economic viability, including cost effectiveness and anticipated return on investment, should guide project selection to ensure financial sustainability. Given these factors, it is strongly recommended that Ethiopia emphasizes thorough and systematic exploration and resource assessment to identify and prioritize geothermal sites with the highest energy production potential, thereby driving effective and impactful geothermal development nationwide.

V. CONCLUSION

With resources exceeding 10,000 MW, Ethiopia's geothermal sector has enormous potential to provide dependable, low-carbon baseload energy. Despite major obstacles such as a lack of qualified workers, weak institutional frameworks, high initial expenses, and competition from alternative energy sources. However, the industry gains from robust government backing, global cooperation, and rising local demand for sustainable energy. To overcome these obstacles, strategic measures like thorough resource assessments, legislative and policy changes, capacity building, the creation of an autonomous geothermal development agency, private sector involvement, and the prioritizing of high-potential sites are crucial. Ethiopia can establish itself as a regional leader in geothermal energy by putting these strategies into practice, taking inspiration from successful global models, and accelerating geothermal development in order to draw in sustainable investment and ensure a future that is low-carbon, resilient, and varied.

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