EAI Endorsed Transactions
on Energy Web

Research Article EAI.EU

Opportunities, challenges and future perspectives of Geothermal Energy in Ethiopia: A Review

Tessafa Abrham Ashagrie[1*] [0000-0001-6773-3880] and Asmare Tezera Admasie[2]

[1] University of Gondar, Institute of Technology, Chemical Engineering Department, Gondar 196, Ethiopia

[2] Bahir Dar Institute of Technology, Bahir Dar University, 272, Bahir Dar, Ethiopia

Abstract

Ethiopia is among the East African regions with huge geothermal energy potential due to the presence of geologically active volcanic and hot spring-featured Rift Valley. However, geothermal energy is at its infant stage of utilization not only in Ethiopia but also in the continent of Africa and globally. Regionally, Kenya is the country with advanced extraction of it for electricity generation followed by Ethiopia in East Africa. Generation of electricity from this largely abundant energy resource has an enormous opportunity for societal and regional economic development though it is not an easy process due to the many challenges of the generation process. In this paper, geothermal energy in Ethiopia and the region, the opportunity, barriers with possible solutions, and future perspective are stated.

Keywords: Geothermal Energy, East African rift valley systems (EARs), opportunities and challenges, future perspectives

Received on 09 November 2023, accepted on 05 January 2024, published on 16 January 2024

doi: 10.4108/ew.4863

*Corresponding author. Email: ashe2082@gmail.com

1. Introduction

Energy is a scarce resource in Africa and the globe as well and at the same time, it is the pillar of social and economic development. Although the continent has a high potential for renewable energy resources such as geothermal, hydro, solar, wind, and biomass, comparatively access to energy is very limited in Africa especially in East Africa including Ethiopia **[1]**. As energy is a crucial factor in a nation's development, access to it will improve productivity, health, and other social needs so that a healthy society, reduced poverty and satisfied needs can be achieved in developing countries through clean, affordable, and reliable energy production. Energy access and use is, therefore, a geopolitical issue, with international politics and economics having an impact on how any given country meets its energy demands because every energy import has a corresponding economic and political connection to transit and processing countries as well as the producing country **[2,3]**.

In Ethiopia and the continent of Africa, compared to conventional energy sources, renewable energy sources that are inexhaustible, affordable, and environmentally friendly, are largely abundant. This resource can make countries in the continent to be energy sufficient, reduce foreign imports and then reduce the cost of import, guarantee sustainable future energy supplies, and help Africa to achieve its economic objectives **[4, 5]**. The continent has huge potential for renewable energy sources like consistent wind movement, yearly flowing water, twelve months of sunshine, and others, and Hydropower is a highly extracted energy potential after traditional biomass and followed by solar and geothermal. Currently, due to the climatic conditions affecting other energy sources and their abundance, Geothermal is among the largest source of power supply in East Africa, mainly in Ethiopia and Kenya **[6,7]**.

Energy supply and access is an integral part of the Development Strategy of the East African countries. The high geothermal resource in the region is estimated at about 15GW of capacity because of Rift Valley which is the tectonically active region that runs through several countries in Eastern Africa **[8,9].** The East Africa Rift system is a continental rift system with volcanic and tectonic activity that covers Kenya, Tanzania, Malawi, Mozambique, Ethiopia, Uganda, Rwanda, DRC, Zambia, and Botswana from all directions **[10]**.

Geothermal energy is energy extracted from the Earth, the hot rocks located deep underground, for electricity generation, heating, and cooling purposes. It is the stored energy in hot rock and fluids that can be accessed by drilling up to a maximum accessible depth of 10km. In a geothermal power generation plant the heat derived from these hot rocks in the form of steam will be converted to electricity through the combined work of the turbine and generator by electromagnetic induction. Development of geothermal energy is increasing globally because geothermal resource is known to lower carbon emissions compared to other renewable sources and are sustainable yearly and regularly **[7-11].** Therefore, this paper aims to present the geothermal energy distribution in the East Africa Rift system, its major potential areas in Ethiopia, the need as well as the limiting factors of its generation. It also presents the possible solutions to be used to generate power from the hot earth in a minimized challenges and future of the geothermal energy generation, development and expansion in Ethiopia.

2. Distributions of Geothermal Energy in East Africa

Due to natural heat from the Rift Valley, East Africa is the main area of exploitation of geothermal heat on the African continent. Democratic Republic of Congo, Kenya, and Zambia were the first three East African countries in order to install and generate geothermal energy where Kenya is a country in the region with better extraction of this untapped potential until recently. Overall, the huge geothermal potential of this region is still unused, and possible to say it's a virgin resource because of the political, economic, social and technological problems that retarded its development **[10,11]**. Some of the EARs countries with their respective geothermal energy potential are presented below.

As seen in Table 1, extracted energy for all sample countries in the region is far from their respective potential, and an effort to extract is highly demanded in the future.

Table 1: Total geothermal energy production potential in some East African countries

	Geothermal Energy (MW)		
COUNTRY	**Potential**	**Utilized**	**Unutilized**
Djibouti	123	50	73
Eritrea	195	70	125
Ethiopia	10,000	217	9783
Kenya	10,000	865	9135
Tanzania	5,000	140	4860
Uganda	1500	140	1360
Rwanda	340	90	250

Source: IRENA (2020), IEA (2019), IRENA (2014), UNECA (2014).

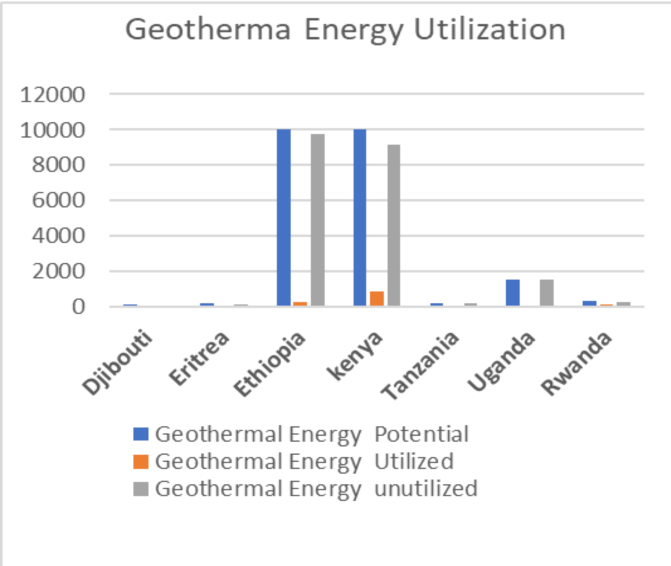

Figure 1: Geothermal Energy Utilization in some East African countries

3. Current Renewable Energy Sources in Ethiopia

Ethiopia is endowed with large renewable energy resources such as solar, hydro, wind, biomass, and geothermal power with an expected generating power of 60,000 MW. The contribution of electricity generated from these sources is greater than 90%. Although traditional burning of biomass has been the primary energy source for most of the society in the country for cooking and heating, hydropower is the major electricity generating source contributing 90% of installed electric power capacity. Currently, the Government of Ethiopia is working to improve its society's access to electricity from 45% in 2018 to 100% by 2030 **[14]**. This will be achieved by expanding renewable energy generation projects such as the Grand Ethiopian Renaissance Dam (GERD), and developing new geothermal projects such as Corbetti, Abaya, Tulu Moye **[12,14,36]**. After proving the huge potential of renewable energy resources in Ethiopia such as geothermal, wind, biomass, solar and hydropower energy, Ethiopia's government has developed a strategy to implement electricity generation from cheap, available, and clean energy resources to meet the energy demand of home, largely agricultural, and industrial activities. Such renewable energy projects can improve access to electricity and reduce the import of fossil fuels **[37]**.

3.1 Geothermal Prospect Areas in Ethiopia

Ethiopia is among the major East African rift valley regions with a great abundance of geothermal energy resources. However, exploration of potential geothermal areas in the country commenced late in 1969 and able to identify the high enthalpy areas which are along the East African rift valleys system such as the Afar depression and the Ethiopian rift valley. The geological survey was made by the Geological Survey, an autonomous federal Agency of Ethiopia, established in 1968 which was later renamed as Ethiopian Institute of Geological Survey (EIGS) in 1984 and back to its original name Geological Survey of Ethiopia (GSE) in 2000. With regard to geothermal energy Geological Survey of Ethiopia made activities such as geological surveying of the potential geothermal areas (surface and reservoir geochemical study); detailed studies such as deep geophysical studies and detailed geological mapping of the prospect areas; hydrochemical and isotopic studies by taking sample water from drilled well, to analysis chemicals, isotopes and gas compositions of the prospect areas and generation of electricity **[13,37]**. After exploration of geothermal potential areas in the country, the Ethiopian rift valleys areas such as Aluto Langano, Corbetti, abaya, Tendaho Ayrobera, Tulu Moye, and Dallol were identified as major resources areas [13,16] as shown in Table 2; which also shows the detailed exploration (red marked) and the reconnaissance surfaces (yellow marked) in the area. Among them, Aluto Langano was the only project producing electricity for a long and recently some projects are generating while others are still under development and the details are shown in Table *2***.** In addition to these projects' identification of prospect areas such as deep geological surveys including hydrochemical and temperature measurements of drilled shallow wells is being performed to boost the generating capacity and utilization efficiency of the abundant thermal energy of the earth **[13]**. Although the geothermal generation capacity of Ethiopia is estimated to be 10,000 MW, only less than 1% of this capacity is utilized and many projects are under development both by the government of Ethiopia and other organizations such as the Kenyan energy agency (KenGen) to upgrade its utilization **[14]**.

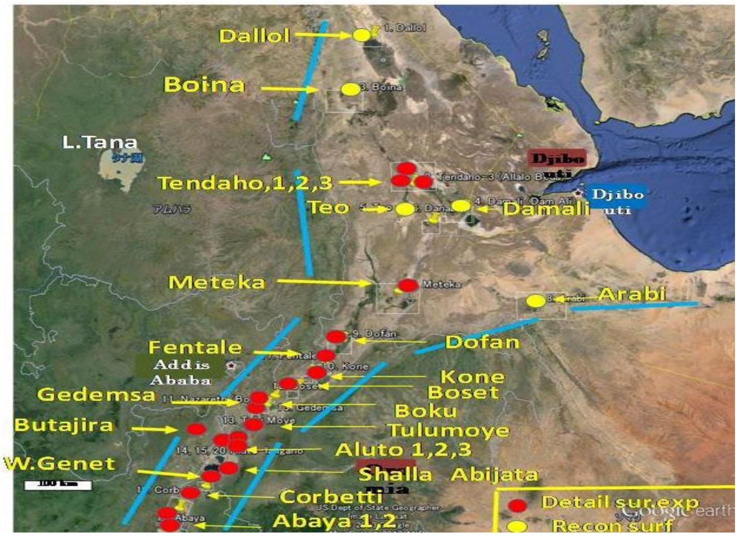

Figure 2: Location of the geothermal prospect areas within the Ethiopian Rift Valley [35].

Table 2**:** Geothermal energy generation projects in Ethiopia **[13-16,35]**.

No	Name of Geothermal energy generation project	Region of project	Potential (maximum Generation capacity) (MW)	Estimated reservoir temperature (°C)	Year of commencement	Expected Year of Commercial Operation
1.	Tendaho Ayrobera	Afar	180	270	2023	2024
2.	Corbetti	Oro	150	250	2022	2023
3.	Aluto-langano	Oro	100	300	1998	
4.	Tulu Moye - Gedemsa	Oro	150	200	2017	2018
5.	Abaya	SNNP	100	>260	2023	2024
6.	Dofan-Fentale	Afar	150	> 250	2017	2018
Total			=830			

(Oro- Oromia region, SNNP- southern nation nationality and population region)

4. Driving Factors for the Generation of Geothermal Energy in Ethiopia

Increased use of geothermal energy can reduce the use of depleting conventional resources and their emission of greenhouse gases as well. The government of all nations has a regulation on energy generation from any source to control its social, economic, and environmental impact. The general critical factors driving its growth in geothermal energy generation are environmental, financial, policy, price, and physical elements such as this limited access to modern energy in the region where only traditional biomass energy sources are dominant and cause health and environmental problems, limited availability of fossil fuels, unstable prices of fossil fuels and growing greenhouse gas emissions, high capacity, and cost-effective geothermal power due to the high potential of the region, reduced pollution from geothermal power plants and growing demand for the energy, enactment of the national policy and Geothermal is preferred source of energy as they produce far less carbon emission and unaffected by drought-like hydropower **[9, 13-16].**

5. Challenges and Potential Solutions of Geothermal Energy Generation in Ethiopia

Geothermal energy resource is highly abundant in East African countries including Ethiopia; however, its generation is well facilitated due to social, economic, technological and governmental constraints. Lack of specialized equipment for geothermal development, **l**imited financial availability, unsophisticated infrastructure such as access to utility and road, limited technical skills, lack of awareness of societies about geothermal energy generation, inadequate private sector participation in the region and lack of a dedicated regulatory framework for geothermal exploration and development are among the main barriers to its generation and future development. The high salt content of reservoir fluid and the hot weather also causes the challenges of aggressive scaling during flashing and problems of lower efficiency to the power generation plant due to higher temperature respectively. These constraints are the real reason for geothermal energy generation to be under development in the East African region **[20-21].**

5.1 Possible Solutions to Overcome the Challenges

Before geothermal energy generation projects are started, there must be a focus on the society and their economic activity around the site in addition to a geological survey as it has an impact on the progress of the project. This stage is therefore an establishment of bonding and interaction between the government, geothermal energy developing company, and the local community in addition to meeting the following solutions for the most common Geothermal energy generation barriers **[20-22]**. Skilled human resources such as Trained scientists, engineers, and technicians, adequate funding and establishing a conductive government policy and a regulatory framework that can support private investments, Application of suitable technology to explore geothermal energy including for faulty areas, Application of evaporative and filtration techniques to remove high salt from the fluid(hot springs), and Access of infrastructure and all required materials useful for energy generation process in order to finish it based on the set plan.

6. Environmental impact, overall risk, and economic benefits (opportunities) of Geothermal energy development

Geothermal energy generation has both positive and negative impacts to society and the surrounding environment.

6.1 Environmental impact

Geothermal energy is one of the emerging technologies in renewable energy generation from renewable resources that extracts heat from the underground Earth applicable for different households and industries. The energy generated from the earth in the form of geothermal energy is quite clean, reliable, and affordable and is mostly preferred source of energy due to its low cost with low-emission nature compared to other sources **[2,17,22-23].** According to the US Energy Information Administration (EIA), this form of energy generation releases far less sulphur and carbon dioxide that causes acidic rain and greenhouse gas effects respectively compared to the same capacity conventional power generation plants**.**
Geothermal energy generation can contribute to a rapid increase in access to energy in East Africa. However, its development and power generation affect the environment, and society through greenhouse gas releases such as CH_4, CO_2, H_2S&NH_3, the release of contaminated water and gas from the generation process, noise, and odour, by changing the land(site) and soil during exploration and construction of the power plant **[22].** However, of most, the above-mentioned effects are ably reduced by the application of suitable and advanced geothermal energy generation technologies, and possible to produce this form of energy with no or less impact on both society and the environment.

6.2 Risks of Geothermal Energy Development

Geothermal energy generation is a physical operation process with some risks besides the benefits it provides. Among the many, major risks associated with it are foreign exchange risk (hedge), natural disasters, confiscation, expropriation, nationalization, currency inconvertibility and transfer restrictions, political and social instability and conspiracy, resource risk, construction risk, environmental and social impact **[21-24]**.

6.2 Economic benefits/ opportunities of Geothermal energy

Not only Ethiopia but also Africa as a continent is still struggling with poverty and limited electricity for many of its citizens. Modern electricity access is the pillar component for economic growth and reduced poverty but due to the lack of electricity in most regions of the continent, about 433 million of its people are living life in extreme poverty in 2018, rising from 284 in 1990 **[24]**. Although the economic development of Ethiopia and the East African region is showing progress, more populous rural areas are where poverty is at its worst stage. This is because these areas are far from the grid connection and inaccessible to electricity having huge potential for geothermal energy and implies how energy and poverty are interdependent. When there is the generation of energy from geothermal sources, there is access to energy(electricity) to industries, hospitals, and schools and there will be improved productivity, access to quality education, and better healthcare service, creating job opportunities for the community and reducing poverty **[7,26]**.

As energy is accessible, the economy will grow, and job opportunities is high. Therefore, when a geothermal energy generation power plant is built and constructed, employability will increase, business activities around the site will be improved due to the trade of services and plant construction materials and generate revenue in the form of tax. Much of the job opportunities will be in drilling and exploration, in generator, turbine, and power component materials manufacturing industries, and in maintenance and generating income in the form of wages and salaries from employment which increase the local and regional economy. Generation of energy from an indigenous resource has also a priceless advantage in reducing import expense and foreign energy dependence because reducing trade deficits keep wealth and promotes healthier economies and then imported oil will be displaced with domestic energy resources [17]. Geothermal energy generation is a sustainable, cleaner, and lower fuel demand process than conventional energy generation process which makes its cost of operation and maintenance very low and predictable. Generally, geothermal energy is a cost-effective, affordable, and stable process after the initial investment costs of discovery and project development. Last but not least, geothermal energy is known for its small area of land for plant construction and keeps the surrounding landscape and ecosystem conserved **[23,25-26].**

7. Future Plans to Use Geothermal Resources

Although there are various barriers as stated above to the development of the high potential Geothermal energy in Ethiopia, expansion of existing projects (Aluto-Langano, Tendaho), new development projects that are under implementation (such as Abaya, Dofan-Fantale), and exploration of the new prospect areas with enough geothermal potential (such as Metaka, Teo, Dallol, kone, Danab, and lake Abhe) are the future plans to extend the utilization of geothermal energy resource in Ethiopia and to improve citizens access to electricity in the country**[13]**.

Conclusion

Energy access is limited for the developing world including the East African region although alternative energy sources are available. Geothermal energy is an untapped renewable energy potential in East Africa that can improve the life of the society and economy of individual countries in the region. However, due to economic, technical, social, and political problems in Ethiopia and the region, this abundant resource is not well exploited and only a few countries have installed geothermal energy generation.

Mainly inadequate finance, social and private sector participation, technical skill, policy, and salinity nature of the reservoir fluid are the constraints as a developing region while the skilled human resources, adequate funding and establishing, appropriate and suitable methods for geothermal exploration, adequate supply of materials for generation process are possible solutions to come over the constraints.

The generation of electricity from geothermal resources is known as an environmentally friendly process which is not true always as it can have an impact on the environment and society during the generation process. The release of Greenhouse gases, soil, and water pollution, and noise pollution are its effects on the environment while social instability, and resource and construction risks are risks associated with the physical operation and natural disaster of the geothermal energy generation process.

Acknowledgment

We would like to extend our gratitude to the EAI International Conference on Power Engineering and Sustainable Energy for opening the opportunity.

References

[1] IEA. (2019). *Africa energy outlook, Paris: International Energy Agency*. www.iea.org/africa2019%0Ahttps://www.oecd-ilibrary.org/energy/africa-energy-outlook_g2120ab250

[2] UNECA. (2014). Energy Access and Security in Eastern Africa. Status and Enhancement Pathways. In *Energy Access in Eastern Africa*. http://www.uneca.org/sites/default/files/publications/energy_access_and_security_in_ea_eng_fin_lowres_27dec2013.pdf

[3] Sawyer, C. (2020). *Meeting Future Electricity Needs in the East African Community: Mapping Renewable Energy Potential.* https://www.diva-portal.org/smash/record.jsf?pid=diva2:1478929

[4] IRENA. (2020). *Geothermal Development in Eastern Africa: Recommendations for power and direct use*. www.irena.org/publications%0ARECOMMENDA

[5] Manfred Hafner, Simone Tagliapietra, & Lucia De Strasser. (2018). Energy in Africa: Challenges and Opportunities. In *Springer Briefs in Energy*. https://link.springer.com/content/pdf/10.1007%2F978-3-319-92219-5.pdf

[6] Mburu, M. (2009). Geothermal Energy Utilisation. *Exploration for Geothermal Resources*, 1–11.
[7] Merem, E. C., Twumasi, Y., Wesley, J., Olagbegi, D., Fageir, S., Crisler, M., Romorno, C., Alsarari, M., Hines, A., Ochai, G. S., Nwagboso, E., Leggett, S., Foster, D., Purry, V., & Washington, J. (2019). Analyzing Geothermal Energy Use in the East African Region: The Case of Kenya. *Energy and Power*, *9*(1), 12–26.
[8] Kombe, E. Y., & Muguthu, J. (2018). Geothermal Energy Development in East Africa: Barriers and Strategies. *Journal of Energy Research and Reviews*, *December 2018*, 1–6. https://doi.org/10.9734/jenrr/2019/v2i129722
[9] Omenda, P., Teklemariam, M., Commission, A. U., & Ababa, A. (2010). *Overview of Geothermal Resource Utilization in the*. 1–11.
[10] Omenda, P. A. (2009). The geothermal activity of the East African rift. *Presented at Short Course II on Surface Exploration for Geothermal Resources*, 1–12.
[11] International Renewable Energy Agency. (2020). *The East African Rift: Realising the Region's Geothermal Potential*. 2–3.
[12] Mazengia, D. H. (2021). *Ethiopian Energy Systems - Potentials, Opportunities, and Sustainable Utilization*.
[13] Burnside, N., Montcoudiol, N., Becker, K., & Lewi, E. (2021). *Geothermal energy resources in Ethiopia : Status review and insights from hydrochemistry of surface and groundwaters*. *June*, 1–27. https://doi.org/10.1002/wat2.1554
[14] Tiruye, G. A., Besha, A. T., Mekonnen, Y. S., & Benti, N. E. (2021). *Opportunities and Challenges of Renewable Energy Production in Ethiopia*. 1–25.
[15] Solomon, K., Fikru, W., Tesfaye, K., & Ababa, P. O. B. A. (2021). *Status of Geothermal Exploration and Development in Ethiopia*. *October*.
[16] Teklemariam, M., & Beyene, K. (2005). *Geothermal Exploration and Development in Ethiopia*. *April*, 24–29.
[17] Garman, D. K. (2004). Geothermal Technologies Program: Buried Treasure-The Environmental, Economic, and Employment Benefits of Geothermal Energy. *U.S. Department of Energy-Energy Efficiency and Renewable Energy*. https://www.holidify.com/pages/hot-water-springs-in-india-128.html
[18] Teklemariam, M. (2008). *Overview of Geothermal Resource Utilization and Potential in the East African Rift System*. 1–9.
[19] Heath, J., Sussman, D., Lonsdale, A., & Bayarsaikhan, M. (2018). *Advancing geothermal development in East Africa: Lessons learned during the 2015-2018 EAGER Programme*. *November*, 13. www.eagerfacility.com
[20] Sutter, J., & Githui, D. (2013). Reasons for and Impact of Having Majorly Geothermal Powered Economy: a Critique of Kenyan Power System. *Thirty-Eighth Workshop on Geothermal Reservoir Engineering*.
[21] Kincer, J. (2021). *5 Major Barriers to Scaling Up Geothermal in East Africa*. *July*, 1–2.
[22] Luketina, K. M. (2022). Environmental Impacts of Geothermal Energy Use. *Comprehensive Renewable Energy*, 72–91. https://doi.org/10.1016/b978-0-12-819727-1.00010-8
[23] Fridriksson, T., Merino, A. M., Orucu, A. Y., & Audinet, P. (2017). Greenhouse Gas Emissions from Geothermal Power Production. *PROCEEDINGS Geothermal Reservoir Engineering*, 1–12. https://pangea.stanford.edu/ERE/db/GeoConf/papers/SGW/2017/Fridriksson.pdf
[24] Njiru, C. W., & Letema, S. C. (2018). Energy Poverty and Its Implication on Standard of Living in Kirinyaga, Kenya. *Journal of Energy*, *2018*, 1–12. https://doi.org/10.1155/2018/3196567
[25] Joint Research Centre. (2020). *Status of Geothermal Industry in East African Countries*.
[26] Urban, F. (2019). Energy, poverty, and development. *Energy and Development*, 1–23. https://doi.org/10.4324/9781351047487-1
[27] IRENA. (2014). A Renewable Energy Roadmap Report. *Irena*, *June*, 173. www.irena.org/remap
[28] Amoah, A., Kwablah, E., Korle, K., & Offei, D. (2020). Renewable energy consumption in Africa: The role of economic well-being and economic freedom. *Energy, Sustainability and Society*, *10*(1), 1–17. https://doi.org/10.1186/s13705-020-00264-3
[29] https://doi.org/10.3389/fenrg.2020.564104
[30] Nalule, V. R. (2019). Energy Poverty and Access Challenges in Sub-Saharan Africa: The Role of regionalism. *Energy Climate and the Environment*, 1–5.
[31] Bonan, J., Pareglio, S., & Tavoni, M. (2017). Access to modern energy: A review of barriers, drivers and impacts. *Environment and Development Economics*, *22*(5), 491–516. https://doi.org/10.1017/S1355770X17000201
[32] www.eia.gov: US Energy Information Administration
[33] Endeshaw, A., & Belaineh, M. (1990). Status of geothermal energy in Ethiopia.
[34] Kebede, S. (2014). Geothermal Exploration and Development in Ethiopia: Country Update. *Short Course IX on Exploration for Geothermal Resources*, *15*(Figure 1), 8.
[35] Teklemariam, M., & Kebede, S. (2010). Strategy for Geothermal Resource Exploration and Development in Ethiopia. *Proceedings World Geothermal Congress*, *April*, 25–29.
[36] Ministry of Water Irrigation and Energy, & Ethiopia Federal Democratic Republic of. (2015). *Highlights of the Ethiopian Geothermal Sector*. *June*. http://www.irena.org/EventDocs/4. Ethiopia.pdf
[37] Teklemariam, M., Beyene, K., AmdeBerhan, Y., & Gebregziabher, Z. (2000). Geothermal Development in Ethiopia. *World Geothermal Congress 2000*, *3*, 475–480.
[38] Simiyu, S. M. (2010). Status of Geothermal Exploration in Kenya and Future Plans for Its Development. *World Geothermal Congress 2010*, *April*, 25–29.
[39] Mnjokava, T. T. (2012). Geothermal Development in Tanzania – A Country Update. *4th African Rift Geothermal Conference, Nairobi 2012*, *Figure 1*, 19–25.
[40] Tucho, G. T., & Kumsa, D. M. (2020). Challenges of Achieving Sustainable Development Goal 7 From the Perspectives of Access to Modern Cooking Energy in Developing Countries. *Frontiers in Energy Research*, *8*(November), 1–11.
[41] https://www.geoenergymarketing.com/energy-blog/geothermal-country-overview-ethiopia.