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Review paper

A Review on Renewable Energy Scenario in Ethiopia

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A B S T R A C T

Although Ethiopia is one of the world's fastest-growing economies, access to sustainable energy and cutting-edge clean energy technology remains a major concern. The government is making significant efforts to generate renewable energy and provide more access to its citizens. Despite this, traditional fuels (charcoal, fuel wood, dung cakes, and agricultural waste) account for around 87 percent of Ethiopia's energy use, and they pose a range of health and environmental risks. Solar, hydro, wind, and geothermal resources abound in the nation, but only 5% of the country's total hydroelectric capacity is being used; while, the rest is either underutilized or underdeveloped. An in-depth look at Ethiopia's renewable energy potential, as well as the opportunities and problems it faces, is presented in this review. With a combined installed capacity of over 7000 MW, hydropower and wind power are the most promising renewable energy sources in Ethiopia as of yet. It is hoped that this assessment will shed light on how Ethiopia can harness and maximize the use of its abundant renewable energy sources.

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NOMENCLATURE

TJ	Terrajoule	Ktoe	Tonne of oil equivalence
KWh/m^2	Kilowatt hour per squre meter	TJ	Terrajoule
MW	Megawatt	KWh/m^2	Kilowatt hour per squre meter

INTRODUCTION

The worldwide demand for energy is expanding at a rate that has never been seen before as a direct result of the rise in the world's population as well as the expansion of industrial activity [1, 2]. Even though there has been significant progress made in the development of renewable energy sources in recent years, fossil fuels continue to hold the greatest share of the market for energy sources [3-5]. Non-renewable fuels are inextricably linked to both the release of greenhouse gases (GHG) and the exacerbation of climate change. However, according to the projections made on the development of major energy sources over the next twenty years, renewable energy will be the principal source of energy with the highest rate of expansion [6, 7]. As a consequence, it will contribute to the reduction of greenhouse gas emissions; therefore, guaranteeing that energy is both reliable and inexpensive. It is anticipated that the world's net electricity generation would rise by 69 percent, from 21.6 trillion kWh in 2012 to 36.5 trillion kWh in 2040, with renewable energy sources contributing 11 trillion kWh of that total [8]. In the future years, Africa, which is one of the continents in the world with the greatest population growth, will be faced with a significant obstacle that is connected to energy difficulties. More than 600 million people in sub-Saharan Africa will continue to lack access to consistent power by the year 2030, while the majority of the remaining population will continue to rely on traditional energy sources [9].

Ethiopia is one of the fastest growing economies in Africa; however, its access to modern energy supplies is one of the lowest in the world [10]. In order to meet the

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ever-increasing demand for power in the nation and to contribute to the fight against climate change, the government of Ethiopia has been taking initiatives and making attempts to utilize renewable forms of energy. One of the agreements that were struck bilaterally was the one that took place in 2017 between the government of Ethiopia and the Italian multinational energy organization, Enel. The purpose of the agreement was to develop and make use of the country's limitless assortment of renewable energy resources (see Figure 1). The mountains of Ethiopia are a rich source of sun irradiations, while the flatlands and lowlands both have strong winds, and the wooded regions have a number of rivers. However, a significant portion of these abundant energy sources remains untapped. In Ethiopia, biomass is considered to be the largest important source of energy, since it accounts for 87 percent of the country's overall energy supply [11]. Nevertheless, the present energy systems in rural and urban regions are quite different from one another in a number of significant ways. When it comes to lighting, around ninety percent of urban populations rely on electricity, in contrast to the nearly one hundred percent of rural families that rely on traditional fuels for cooking [12]. In spite of the country's significant reliance on conventional sources of energy, it is making slow but steady progress in lessening its reliance on non-renewable energy sources and shifting the focus instead toward a supply of energy that is both clean and renewable. Given the rapidly expanding economy and the improving state of infrastructure, the demand for energy is currently skyrocketing at an alarming rate [13].

This review's objective is to contribute to the existing body of knowledge on energy resources by investigating the prospective energy resources that renewable energy is derived from and the current state of utilization of such resources in Ethiopia. The growing number of people in Ethiopia, like in most other regions of the world, has led to an increase in the demand for energy in the country. As a result, it has become necessary to investigate other potential sources of energy. Building on a recent review papers on the status of renewable energy development in Ethiopia, where only succinct information is given on the challenges and progress made in Ethiopia's RE industry [10-12]. This review offers a thorough analysis of renewable energy sources along with comments on the availability, types, potential, opportunity, and constraints associated with the budding sector. Summarily, this article provides readers with more detailed information on the development of renewable energy sources in Ethiopia, namely biomass, wind, biodiesel, hydropower, residue and dung, waste-to-energy, geothermal, and solar energy for electricity and heat generation. In addition to this, the review provides an analysis of the policies now in effect in Ethiopia with regard to enabling the transition and uptake of renewable energy. Findings from this study will assist policy makers and potential investors in deciding on which renewable sources has the greatest technical, environmental, and economic advantages to throw their support behind in addressing or at least mitigating the country's current pollution and energy challenges. Furthermore, researchers with interest in Ethiopia's renewable energy sector could use the present study's findings as a foundation for further research and development.

MATERIAL AND METHODS

The literatures used for this work were sourced from reputable databases (Springer, Science direct, SCOPUS, Web of Science, ProQuest and Google Scholar).

Current energy scenario in Ethiopia

Ethiopia is one of the countries in the world that suffers from an energy deficit, making it a net importer of energy. The country is naturally endowed with a variety of renewable energy sources and has the potential to generate up to 45,000 MW of renewable energy from hydropower; 10,000 MW from wind energy; 5000 MW from geothermal energy; and an average of 5.26 kWh per square metre per day from solar energy source. However, this potential is not being completely tapped [14]. Except for the biomass fuel, most of the presented energy source is either untapped or not fully developed. For instance, Ethiopia is now rated second in Africa behind only the Democratic Republic of the Congo (DRC) in terms of its hydroelectric potential [15]; nevertheless, it has only harnessed around ten percent of its entire capacity. Ethiopia is one of the nations in sub-Saharan Africa that has the potential to be a center for renewable energy, despite the fact that its citizens have limited access to energy. Table 1 summarized Ethiopia's energy potential.

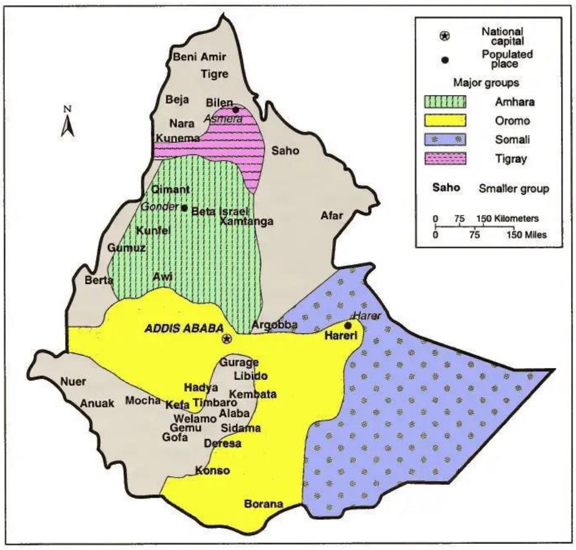

Figure 1. Map of Ethiopia [16]

Table 1. Ethiopia's domestic energy resources and their current state [14]

Resource	Unit	Potential	Exploited
Hydropower	MW	45,000	<10%
Wind	MW	10, 000	<1%
Geothermal	MW	10,000	<1%
Agriculture Waste	Million tone	15-29	<30%
Firewood	Million tone	1120	<30%
Biomass	Million metric ton/Year	75	<50%

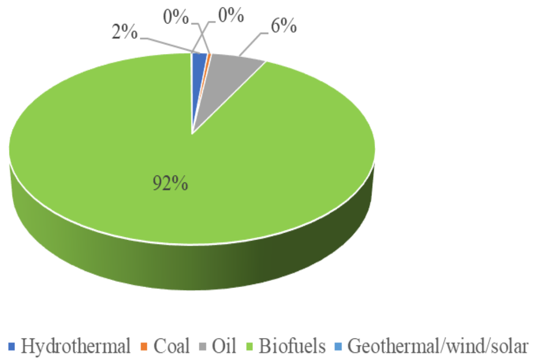

Figure 2. Ethiopia's share of total primary energy in 2015 [18]

In Ethiopia, as in many other African nations, residential users have a significant reliance on energy sources that are derived from biomass [17]. Waste and biomass provide the most energy, accounting for up to 92.2 percent of total primary energy supply, followed by oil (5.7 percent) and hydropower (1.6 percent) (see Figure 2) [13]. In comparison to the urban region, where 92 percent of homes have access to electricity, rural coverage is only 32 percent. This puts the rural area at a significant disadvantage. Reports indicate that, as of 2019, 55.2 percent of Ethiopians did not have access to electricity [18]. The goal of the Government of Ethiopia is to raise the percentage of people in the nation who have access to electricity from the reported 45 percent in 2018 to 100 percent in 2030, with an annual increase in access of 1.7 percent from 2010–2019 [19].

Demand and generation capacity of energy in Ethiopia

In Ethiopia, biomass energy sources are the major and primary sources of energy consumption. As of the year 2017, traditional fuels, which include charcoal, fuel wood, dung cakes, and agricultural leftovers, accounted for around 87 percent of the overall energy sources [20]. People who live in more remote parts of the country typically rely on fuelwood and other byproducts of tree cuttings rather than the nation's electrical grid for the majority of their lighting and cooking needs [21]. On the contrary, modern fuels accounted for approximately 13% of the total amount of energy that was consumed in the year 2017, with hydrocarbon products accounting for 80% of this total (light petroleum products accounting for 25%, heavy petroleum products accounting for 47%, and coal accounting for 8%), and electricity accounting for 15% [21]. According to a report compiled by the govenment, the total amount of energy that the country consumed in 2017 was 41,461 ktoe, which represents a 4% rise over the previous year's figure of 39,701 ktoe [10]. In 2017, the total amount of energy consumed by all parts of the economy was 38,964 ktoe, of which 3% (1227 ktoe) was comprised of light petroleum products (MGR, LFO, Jet fuel, LPG, ethanol, and kerosene), 6% (2292 ktoe) was comprised of heavy petroleum products (ADO and HFO), 2% (375 ktoe) was comprised of hard coal, 2% (738 ktoe) electricity and 88% (34,085 ktoe) biomass [22]. A significant amount of energy is consumed by the residential sector, which accounts for 88.2 percent, followed by the transportation sector, which accounts for 8.4 percent. The majority of the energy that was used in homes came from biomass, which accounted for 88 percent of total consumption. The remaining 9.26 percent was made up of the use of electricity and petroleum products combined. Petroleum fuels made up 82.97 percent of the transportation sector's total energy consumption, while bioethanol made up 17.03 percent. The remaining resources were utilized by the industrial, construction, and service sectors [23, 24].

Ethiopia is endowed with enormous renewable energy resources, including a big potential for hydro, solar, wind, bio, and geothermal power. Ethiopia is also home to a number of additional types of alternative energy. It is one of the few nations in sub-Saharan Africa, if not the globe, that generates more than 90 percent of its energy from conventional sources [25]. Ethiopia's energy demand and electrification rate are aided by abundant renewable energy resources, including hydro, solar, wind, bio, and geothermal power. Ethiopia currently has 4244.67 MW of installed total power production capacity, the majority of which is accounted for by hydropower. However, there are significant disparities in access to power in urban and rural communities [26]. This means that the majority of the country's population (>50 percent) does not have access to electricity. However, the trend reveals that the electrification rate, which is largely carried out by the Government of Ethiopia, has climbed from 5% in 2000 to 45 percent in 2016, resulting in thriving off-grid access in rural areas. The growth of generation capacity, both currently underway and planned for the future, will continue to rely only on non-depletable sources.

The Ethiopian government has prioritized the development of a sizeable number of megaprojects utilizing renewable energy sources including hydropower, wind power, and solar power during the course of the past twenty years [27]. Despite the fact that Ethiopia's energy system has not grown in synchrony with the expansion of its economy, nor with the rapid rate at which its population is urbanizing, nor with the anticipated increase in energy consumption in the foreseeable future. The demand for electricity in all areas of the Ethiopian economy would likewise expand at an exponential rate [28].

Policy and regulatory framework for renewable energy in Ethiopia

The government of Ethiopia has adopted a proactive strategy to reduce carbon dioxide emissions and encourage the expansion of renewable energy. Due to the fact that the majority of Ethiopia's energy consumption is satisfied by conventional energy sources, the Ethiopian government has been engaged in a number of initiatives over the past two decades by enacting a variety of policies that are connected to energy production, distribution, and electrification. The use of hydropower, solar power, and wind power as sources of energy is given special consideration [29]. The overarching goal of Ethiopia's national energy policies and strategies is to strengthen and accelerate national efforts centred on the efficient, equitable, and optimal propagation and utilization of available energy resources for significant socioeconomic development and to help promote the country's economic advancement [30]. Beginning in 2010, the government of Ethiopia has developed a detailed national strategy that is being referred to as the Growth and Transformation Plan (GTP-I and GTP-II). The Growth and Transformation Plan's primary focus is on energy policy.

Both the GTP-1 (which covered the years 2010–2014) and the GTP-II (which covered the years 2015–2020) are examples of short-term national plans that contain energy strategies [31]. The primary goals of the energy policy are to ensure a reliable supply of energy; encourage a considerable shift from conventional energy sources to clean and renewable energy sources; and prioritize the growth and propagation of nature-based energy resources. All of these goals are interconnected and must be accomplished in order for the energy policy to be successful. Even though the present total quantity of energy production is far lower than the amount that is anticipated, the energy strategy that is included in the GTP-II plan includes the generation of energy from a variety of renewable sources.

The energy industry is listed as one of the priority sectors to construct a climate-resilient circular economy by 2030 in the current ten-year developmental national plan, also known as "Ethiopia 2030: The Pathway to Prosperity (2021-2030)." The current national 10-year development plan's energy focus areas include equity in access to electricity services; energy access and quality, alternative energy sources; electricity infrastructure reliability, investment and income in the energy subsector [32].

Renewable energy resources in Ethiopia

Ethiopia has an abundance of renewable energy resources with the ability to generate approximately 60,000 MW of electricity only from hydropower, wind, geothermal, and solar energy [33]. Ethiopia has placed a primary emphasis on the production of renewable energy and is actively involved in the development of its renewable energy potential. This is done with the goal of achieving economic growth and development. Wind power, solar power, geothermal power, and biofuels are some of the forms of renewable energy sources that are being utilized in Ethiopia [34].

Hydropower

With a massive hydropower potential that is predicted to reach up to 45,000 MW, Ethiopia is widely considered to be the logical counterpart to the Democratic Republic of the Congo as the Water Tower of Africa. Many of the nation's water resources are suitable for the generation of hydroelectricity, ranging from tiny to grand hydro power plants, as a result of the hilly terrain that dominates the majority of the country's geography. Ethiopia boasts eleven major river basins, among which eight have been identified as having the potential to generate hydroelectric power, with a combined capacity of 159,300 giga Watt hours per year [35]. There is potential for the installation of around 300 hydroelectric facilities in eight basins, 102 of which are large scale (more than 60 MW) and 198 of which are small scale (less than 40 MW) [10]. Ethiopia's hydroelectric power plants account for 92 percent of the country's overall ability to generate electricity, making them the primary contributor to the country's total installed electric power capacity [36]. Ethiopia has embarked on a series of remarkable energy projects costing multiple billions of dollars in order to meet its surging demand for additional energy. These projects are mostly focused on the generation of renewable energy and include a variety of hydropower plant projects. Some examples of these projects are the >5 GW GERD on the Blue Nile river and the 254 MW GenaleDawa Dam on the Genale river. At the moment, Ethiopia has erected 17 hydropower plants that are connected to the grid, of which 14 are Inter Connected System (ICS) and 3 are Self-contained System (SCS), with a combined installed capacity of 4067.759 MW [37].

The small hydropower self-contained system (SCS), which is comprised of three different small hydropower plants, is put into operation in outlying regions that are held privately by institutions. Despite the existence of a large number of small rivers and waterfalls that might be used for the generation of energy to service additional off-grid communities in rural areas of Ethiopia, the contribution from the small hydropower plants is only approximately 6 MW. Due to the fact that the overall cost of energy produced by SCS power plants is greater when compared to that produced by ICS power plants, small hydropower projects are often only viable in areas that are cut off from the national grid [38]. In Ethiopia, the majority of energy will continue to come from hydropower generation over the next ten years. This will make hydropower the country's primary source of electricity [39].

Biomass resources

In developing countries, particularly in sub-Saharan African countries like Ethiopia, biomass is regarded as the primary source of energy because of its abundant supply, accessibility and zero to cost effectiveness [40]. Biomass is a natural resource that is utilized all over the world for a wide variety of applications, but the two most common ones are lighting and cooking [41]. Biomass resources are comprized of waste from municipal and agricultural operations. Wood, agricultural residue, urban and industrial trash, and animal waste are the several types of waste that may also be used as sources of biomass energy in Ethiopia [42]. It is predicted that around 153.4 million tonnes of energy may be obtained yearly from bio-energy resources [10]. This represents the entire amount of energy that can be consumed. The proportion of this that is comprised of woody biomass is estimated to be 73% (wood 69% and charcoal 4%), followed by the proportion that is comprised of animal faeces (14%), and then by the proportion that is comprised of residue (13 percent) see Figure 3. The majority of the rural population is dependent on woody biomass, agricultural leftovers, and animal manure, all of which may be readily harvested. However, use is still not being balanced, since the rate of consumption is larger than the rate of re-plantation [43].

Fuelwood

Fuelwood is the most important source of energy in Ethiopia, and it is utilized extensively across the country, both in rural and urban settings, for the purpose of food preparation and a wide variety of heating applications [44]. Firewood that is harvested in a sustainable way facilitates the storage of carbon dioxide. When fossil fuel is replaced with sustainably generated firewood, there is a 2–3 kg decrease in CO^2 emissions for every kilogram of fossil fuel that is used [45]. This indicates that utilizing sustainably obtained firewood as a source of energy is carbon neutral. The use of primary energy in the form of woody biomass fuel accounts for the majority of total energy use in Ethiopia [46]. The natural forests, which are the primary suppliers of wood products, provide more than ninety percent of the nation's supplies of industrial wood and fuel. The majority of the wood used is used for fuel, and the majority of Ethiopians, in both rural and urban regions, prefer to burn fuel wood as their primary home fuel source [47]. In 2016–2017 fiscal year, it was estimated that the yearly output of firewood (including both commercial and non-commercial firewood) amounted to around 1.2 tera Joule on average [48]. The amount of firewood that was consumed was about identical. The imbalance between the supply of wood fuel energy and the demand for it is putting a significant amount of pressure on the remaining forests and vegetation stocks. This, in turn, is speeding up the processes of land degradation and deforestation, which together are the most significant contributor to greenhouse gas emissions in the country [49].

Charcoal, on the other hand, is an essential fuel, particularly for people who live in metropolitan areas [50]. The average annual consumption of charcoal is expected to be 230,000 tonnes, with urban areas accounting for 70% of all charcoal consumption. In spite of the fact that cutting down trees for fuel leads to deforestation, the demand for charcoal has increased at a quicker rate as a result of the growth in urbanization and the increasing economic efficiency scores of up to 80 percent [51]. In Ethiopia, it is possible to learn from the experiences of European countries in order to improve the viability of wood fuel as an energy source. According to the findings of a study that was carried out in Greece, priority should be given to the production of specific kinds of timber that have high heating properties (woods that have high heat capacity) [51]. According to Palaiologou et al. [52] through a programme called "Green Legacy Initiatives," which the Prime Minister of Ethiopia launched in 2018, the Ethiopian government has launched a tree-planting effort with the goal of reducing the effects of climate change and reversing deforestation. In our view, the cultivation and protection of certain kinds of trees that have a high energy density should be made priority in Ethiopia.

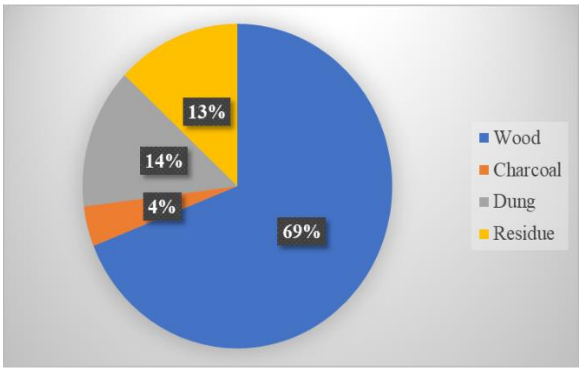

Figure 3. The proportion of different biomass resources used as fuel in Ethiopia [43]

Residue and dung

Cooking and baking in rural households typically involves the use of agricultural leftovers, and the stoves used for these activities have relatively low levels of efficiency [53]. The country has a variety of agricultural wastes that are offered for sale, including coffee husk, cotton stalk, sesame husk, and khat stem, among others. The overall consumption of residues in rural regions is estimated around 19.3 million tonnes per year, while the total consumption of residues in urban areas is just 0.4 million tonnes per year [54]. One of the most prevalent traditional biomasses used by families for cooking is dung cake, which is animal dung that has been compressed into cake shape. In addition, animal excrement may be utilized in the generation of biogas [55]. Households in certain rural areas of the nation are where the process of producing biogas from animal manure and other organic matter is initiated. A survey conducted by the CSA in 2009–2010 estimates that there are around 150 million cattle in the nation [56]. It has been determined that the overall cattle population generates around 42 million metric tonnes of excrement every single year. The greatest proportion of dung production, which is around 84 percent on an annual basis, is attributable to cattle, which includes cows and oxen [57].

The annual consumption of dung in rural regions is estimated to be 20.7 million tonnes, whereas the annual consumption of dung in urban areas is estimated to be 2.1 million tonnes [58]. In addition, decentralised energy initiatives that entail the production of biogas from animal waste are now in the works. The nation now has more than 860 biogas digesters that have been installed [59]. It has a tremendous potential in animal waste and cow dung, and the benefits of biogas technology are high of importance. As a result, installing biogas technologies in the rural homes can pave the way for sustainable energy generation and consumption without being linked to the national grid.

Municipal solid waste and waste-to-energy

The management of solid waste is a significant difficulty that practically all cities and towns, particularly in developing nations like Ethiopia, are currently confronted with [60]. In addition, waste is a primary contributor to a wide variety of environmental and health concerns [61]. On the other hand, wastes' have the potential to become wealth if they are managed and exploited efficiently. The production of methane gas, which may later be converted into energy, can be accomplished through the use of municipal solid waste [62]. The technology that can convert waste into energy has reached an advanced stage of development and has been used in a variety of settings around the globe [63]. methane is also one of the prospective bioenergy resources of Ethiopia that is collected with the aid of landfills in a number of the country's cities and towns. The number of people living in a city is one of the primary factors that determines how much municipal solid waste is produced [64]. The majority of the country's cities and towns, including the nation's capital of Addis Ababa, have a significant population. It is predicted that rural parts of Ethiopia generate between 0.6 and 1.8 million tonnes of solid waste annually, whereas urban areas generate between 2.2 and 7 million tonnes of solid waste annually [65]. For instance, the daily average generation rate of municipal solid waste in Addis Ababa is 0.45 kg per capita per day [66]. Unfortunately, only around 65 percent of the waste that is created every day is collected and disposed of in an appropriate landfill. Five percent of the waste is recycled, and another five percent is composted; the remaining waste is not collected and is dumped improperly, which is a shame.

In very recent times, a new waste-to-energy facility known as Reppie was constructed with the sole purpose of producing around 25 MW of power from waste [19]. At the launch in 2018, it was reported that this plant is Africa's first waste-to-energy facility and has the capacity to incinerate municipal solid waste of one thousand tonnes each and every day. This accounts for around 80 percent of the waste in Adis Ababa. The construction of the waste-to-energy plant cost $95 million dollars.

Bioethanol and biodiesel production

Both the transportation and residential energy sectors in Ethiopia have made use of biofuel production as a source of energy in recent years [67]. The majority of the bioethanol that has been produced from sugar mills has largely been used in the transportation industry [68]. There are now three bioethanol blending facilities in Ethiopia. These plants are operated by Nile Petroleum, Oil Libya, and National Oil Company [69]. Sugarcane bioethanol production is less costly since the fermentation process is often completed relatively quickly. Ethiopia has arable soils, climate, and abundant water resources for sugarcane production [70]. There are roughly 700,000 hectares of land that have been classified as being appropriate for sugarcane plantations, and there are now over a half a million hectares of land that are designated for sugarcane cultivation [71]. Molasses, a by-product of sugar production, is the starting material for the production of bioethanol [72]. One tonne of crushed cane yields around three to four percent final molasses, and one tonne of molasses can yield approximately two hundred and fifty litres of bioethanol [73]. About 20.5 million litres of bioethanol was delivered to the country's energy system in 2014/15, and it was completely utilized in the transportation sector [74]. The Ethiopian sugar corporation has planned to increase the annual production of bioethanol to 28.1 million litres by the end of the second GDP from the existing factories and the others like; Tandaho and Wonji/Shewa expansion projects, and from recent sugar factories [75]. They intend to achieve this goal by utilizing a combination of recent sugar factories and those that already exist. The majority of sugar mills also create electricity from bagasse, a byproduct of sugar manufacturing that is produced alongside sugar and bioethanol [76]. Bagasse is burned to produce energy, which is then utilized to generate steam and produce electricity for the company's own usage as well as for connection to the national grid for power. Sugar mills like Tendaho, Wonji/showa, Fincha, and Metehara each have the ability to generate 60 MW, 31 MW, 31 MW, and 9 MW of electrical power, respectively

[21]. The Metehara sugar plant generates 9 MW of electrical power, all of which is consumed by the facility itself as shown in Figure 4. Tendaho, Wonji/showa, and Fincha have been adding 38, 20, and 10 MW of electric power to the national electrical system, respectively [21].

Through a process called transesterification, which requires the presence of alcohol and a catalyst, biodiesel is produced from a variety of plant and animal sources [77]. The oils that work well and are utilized the most frequently in Ethiopia are palm oil, castor bean oil, and oil extracted from Jatropha curcus [78]. The nation possesses a significant capacity for the production of biodiesel, which is estimated to be between 5 and 10 million tonnes annually [79].

Wind

Since Ethiopia is a landlocked nation, there is nowhere along its coastline for there to be a major wind farm. However, the nation experiences a substantial number of windy conditions due to its geographical location: the summer monsoon, tropical Easterlies, and local convergence over the Red Sea. In addition, Tana Lake, mountains, hills, plains, and valleys in the mountains all have characteristics of locations that are favourable for the generation of wind energy [12]. As a consequence of this, Ethiopia wields a massive quantity of wind energy potential, which is estimated to be 1,350,000 MW [80]. Regions that are only moderately suited for wind power are also included in the gross wind energy potential [12]. An earlier study measured the average monthly wind speed at six distinct locations and reported its findings as follows; Addis Ababa (09 "020 North, 38"420 East, 2408 Meters), Mekele (13 "330 North, 39"300 East, 2130 Meters), Nazret (08"320 North, 39"220 East, 1690 Meters), Debrezeit (08"440 North, 39"020 East, 1850 Meters), Debre Markos (10"200 North, 37"430 East), and Dejen district (24.03"130 North) [81]. According to the findings, the average monthly wind speeds in Addis Ababa, Mekele, and Nazareth, as well as Debrezeit, Debre Markos, and Dejen, are correspondingly 4.2, 3.8, 4, 2.5, 3.7, and 3.1 metres per second. Over the summer months (June, July, and August), the average wind speed in various cities, including Addis Ababa, Mekele, the Dejen area, and Debrezeit, is much lower when compared to the average wind speed in Debre Markos and Nazareth during the same time period [81].

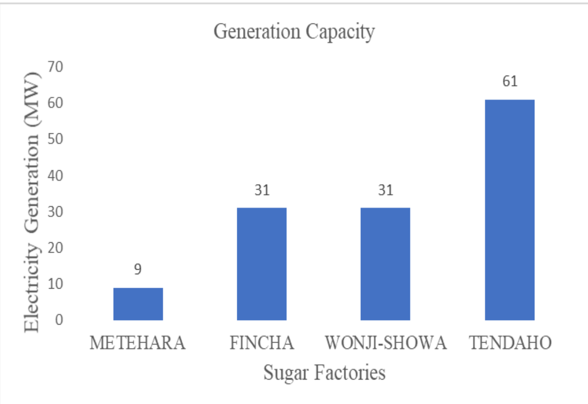

Figure 4. Energy production capacity from bagasse in Ethiopia [21]

As it stands, there are just three wind farm power facilities that are now operational. These are the Adama I, Ashegoda, and Adama II wind farms. The total installed capacity of these power plants is 324 MW [82]. In addition to this, there are a variety of wind farms around the country that are now under development and have plans to begin operations in the not-too-distant future (Table 2).

Solar

The annual average irradiance in Ethiopia is estimated to be 5.2 kWh/m^2/day [82] which indicates that the country has a wealth of solar energy resources. The changes in irradiance that occur throughout the year as a result of seasonal noticeable changes in the country range from 4.5 kWh/m^2/day in July to 5.6 kWh/m^2/day in February and March [83]. This variation in solar resources is mostly a reflection of the different regions of the country. For example, the solar resource in the Central and Western highlands of the country is relatively lower, whereas the solar resource in the North-Western, Eastern, and Rift Valley lowlands of the country receives higher annual average irradiance well above 6 kWh/m^2/day, which is relatively consistent throughout the year [83]. Deducing from Hailu and Kumsa [82], it was found that the months of June through September had the lowest average solar radiation, which ranged from 4 to 5.6 kWh/m^2/day. On the other hand, the months of October through May had the highest average solar radiation, which ranged from 5.6 to 7 kWh/m^2/day. This number is in line with the yearly irradiation average for the tropical zone, which is where

Table 2. Installed and underdeveloped wind farms in Ethiopia [10]

Name of power plant	Installed capacity	UNIT	Date of commissioning
Adama I	51	MW	2012
Ashegonda	120	MW	2012
Adama II	153	MW	2014
	Underdevelopment		
Adama III	150	MW	
Ayisha	300	MW	
DebreBirh wind farm	100	MW	
Asela	100	MW	
Messebo	42	MW	

Ethiopia is located, thus, somewhere around 2000 kWh/m^2 [82].

In spite of the vast solar power resources available, the country has not yet constructed a solar power plant that is connected to the national grid, with the exception of several off-grid photovoltaic (PV) systems that were placed in rural areas starting in the middle of the 1980s. To summarize, off-grid residential and telecom applications account for 87 percent and 13 percent, respectively, of Ethiopia's total installed PV capacity [84].

Geothermal

Ethiopia is one of the few African countries with a considerable potential for geothermal energy resources, making it one of the most attractive geothermal energy investment destinations [82, 84]. The year 1969 marked the beginning of Ethiopia's long-term geothermal energy exploration. The Rift Valley in Ethiopia contains a large number of inventory sites that are thought to contain prospective geothermal energy resources. More than sixteen of these sites are evaluated to have the potential for high enthalpy resource development, which includes the generation of electricity.

Even though Ethiopia has access to a substantial number of geothermal resources, most of them are still exclusively used in traditional ways by the people who live there, primarily for hot springs and steam baths. For example, the state operates large-scale recreational facilities like a swimming pool at Sodore, which is located close to the city of Nazareth. Additionally, there are hot spring bathing facilities (also known as "fil wuha") available in Addis Ababa, the nation's capital. In addition, there is a facility run by the state that functions as a sanitarium, and in Boku, in the vicinity of Nazareth city, there are local steam bathing facilities. Geothermal technologies only account for a minor portion of Ethiopia's overall power supply, but they are potentially alluring possibilities when sufficient resources are available. According to recently conducted research, the geothermal energy potential in Ethiopia is around 10,000 MW [23]. In Ethiopia, the Aluto-Langano geothermal power station, which was constructed in 1999, is the sole geothermal power producing facility. It is one of the 16 geothermal potentials that have been identified. At the moment, its ability to generate electricity is 7.3 megawatts. A recent announcement made by the government of Ethiopia detailed the development plan for six projects that are expected to be finished in the not too distant future, with a total installed capacity of 450 MW. As can be seen in Table 3, the government of Ethiopia has planned to increase the contribution of geothermal energy to the country's present energy consumption, which is mostly reliant on hydroelectric energy. The government of Ethiopia has inked a deal with two businesses to generate a total of one thousand megawatts (MW) from two geothermal locations. This is part of the Government of Ethiopia's initiative to increase energy output from geothermal sources i.e.Corbetti and Tulu Moye [85, 86].

CHALLENGES TO DEVELOPMENT OF RENEWABLE ENERGY

In general, the primary problems of exploiting renewable energy sources in Ethiopia may be divided into three categories: technological, economic, and environmental.

Technological challenges

Despite significant technological advancements in recent decades, there are still several technical impediments to using technology. The quality of the systems employed is critical in the integration of renewable resources in Ethiopia’s energy mix. For example, in photovoltaic solar systems, a key obstacle is limited expertise and availability of parts, a limitation which is likely to result in poor utilization and a lack of capability in maintaining the systems [16, 87]. Furthermore, the lack of an energy storage system, particularly for some renewable energy technologies, has been cited as a major technological issue for solar energy. However, because Ethiopia relies on large reservoirs to generate hydroelectric power, a PV-based pumped storage hydropower system can provide significant flexibility in terms of addressing residual output fluctuation (the difference between demand and non-dispatchable power production).

For some renewable energy sources, such as biodiesel, geothermal, and wind farms inter alia, there are only a few accessible experts as well as competent labour and land, resulting in the observed stymieing of renewable energy’s advancement and market entry in Ethiopia. This situation is primarily due to the flow of highly educated professionals from poor nations to developed countries.

Economic challenges

The reluctance of the majority of Ethiopian banks to support technological investment in various kinds of renewable energy generation has been a major economic obstacle. Because of the high costs associated with the building of production plants, most financial institutions regard renewable energy generation as a potentially risky

Table 3. Geothermal power facilities and their scheduled year of commission in Ethiopia [88]

Name of power plant	Installed capacity	UNIT	Date of commissioning
Abaya	75	MW	2020
Dofan	60	MW	2020
Tulu moye	40	MW	2020
Corbetti	75	MW	2020
Tendaho	100	MW	2020

Business [89]. This difficulty has had a negative impact, particularly on the solar energy market. Furthermore, even if solar PV prices have fallen to a fair level in recent years, this viewpoint makes it difficult to justify the investment. Making economic comparisons between renewable energy and non-renewable energy sources, such as fossil fuels, to electricity has been one of the biggest obstacles in implementing certain renewable energy generation technologies. Ethiopia has attempted to reduce the cost of electricity by combining non-renewable energy with renewable energy-producing technologies. In this aspect, energy costs are becoming more affordable and accessible to the majority of households.

The use of large-scale crop production for energy is also a major concern in various developing countries. When rich fields are exploited to grow energy crops rather than food for human sustenance, problems ranging from hunger to poverty occur. There is a hazy barrier between the energy and agriculture sectors in several African countries, which becomes an issue when individuals are compelled to invest. For example, since the introduction of jatropha to peasant farmers, there has been an observable drop in agricultural productivity in Ethiopia. Many farmers have become economically impoverished, resulting in family famine.

Environmental challenges

The percentage of Ethiopia that is covered with forest is roughly 14%, because of environmental constraints, a significant portion of these forest resources are difficult or impossible to access. It is predicted that the annual demand for fuel wood will be 35 million tonnes, while the annual supply will only be 15 million tonnes [90-93]. The exceptionally significant shortfall in supplies has resulted in an increase in the rate of deforestation of both exotic and indigenous plant life. As a consequence of this, adverse effects on the environment have been caused, including, amongst many others, starvation, drought, land degradation, and desertification. The Ethiopian government established a national improved cookstove programme (NICSP) which aims at supporting the distribution of 11 million improved cookstove (ICS) within 5 years (2016–2020), most of which are designed to bake Injera efficiently. Despite this, the vast majority of people are still dependent on wood for their culinary needs. To this day, over eighty percent of the world's population still prepares food using the age-old method of employing three stones [94].

CONCLUSION

The use of fossil fuels and other non-renewable energy sources is a major contributor to greenhouse gas emissions and global warming in Ethiopia, as it is in many other developing countries. However, renewable energy sources, including geothermal, solar, biomass, wind, and hydro, have huge promise in the country. The Ethiopian government has realised this opportunity and is working to explore and utilize renewable energy sources, such as the $4.5 billion hydropower project, which, at 6,450 megawatts of installed capacity, will be the largest hydroelectric project in Africa. The renewable energy industry in Ethiopia has the potential to generate about 60,000 MW of renewable energy from hydro, wind, solar, and geothermal sources, thanks to the country's rich natural resources. Ethiopia is a promising market for renewable energy due to its political stability and supportive regulatory environment. The rising need for energy in the country presents a huge market for renewable power. From the review, Ethiopia's most promising renewable energy sources in the near future are hydropower and wind power.

CONFLICT OF INTEREST

The authors declare no conflicts of interests/ competing interests.

Availability of data and material (data transparency)**:** All data used in the study will be readily available to the public.

Code availability (software application or custom code)**:** All software applications used in this study were the licensed software applications used by the University for Development Studies, Ghana and the University of Mines and Technology, Ghana.

Consent to participate: The authors consent to participate in this research study.

Consent to publish: The authors consent to publish the findings of the research.

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Persian Abstract

چکیده

اگرچه اتیوپی یکی از سریع‌ترین اقتصادهای در حال رشد جهان است، دسترسی به انرژی پایدار و فناوری‌های پیشرفته انرژی پاک همچنان یک نگرانی اصلی است. دولت تلاش های قابل توجهی برای تولید انرژی های تجدیدپذیر و دسترسی بیشتر به شهروندان خود انجام می دهد. با وجود این، سوخت‌های سنتی (زغال‌سنگ، چوب سوخت، کیک‌های سرگین و ضایعات کشاورزی) حدود ۸۷ درصد از مصرف انرژی اتیوپی را تشکیل می‌دهند و طیفی از خطرات بهداشتی و زیست‌محیطی را به همراه دارند. منابع خورشیدی، آبی، بادی و زمین گرمایی در کشور به وفور یافت می شود، اما تنها ۵ درصد از کل ظرفیت برق آبی کشور استفاده می شود. در حالی که، بقیه یا کم استفاده هستند یا توسعه نیافته اند. نگاهی عمیق به پتانسیل انرژی های تجدیدپذیر اتیوپی، و همچنین فرصت ها و مشکلاتی که با آن مواجه است، در این بررسی ارائه شده است. با مجموع ظرفیت نصب شده بیش از ۷۰۰۰ مگاوات، نیروگاه های آبی و بادی امیدوارکننده‌ترین منابع انرژی تجدیدپذیر در اتیوپی تاکنون هستند. امید است که این ارزیابی روشن کند که چگونه اتیوپی می تواند از منابع انرژی تجدیدپذیر فراوان خود استفاده کند و به حداکثر برساند.