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RESEARCH ARTICLE

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The State of Renewable Energy in Kenya with a Focus on the Future of Hydropower

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Abstract

The rise in global energy demand and the need to reduce greenhouse gas emissions have necessitated the transition to renewables. Many previously unelectrified countries in Sub-Saharan Africa have joined the race to provide their people with clean, reliable, and affordable energy. Kenya is amongst the countries that are leading in powering their energy demands from renewables with over 80% of its energy being green. As economic development advances toward fulfilling Vision 2030 targets, the country's electricity consumption, as well as the end-use of energy, has increased significantly during the last decade. To achieve universal access to electricity and a complete transition to renewables, not only must energy sources be diversified, but they must also be fully exploited. This study aims to highlight Kenya's current energy situation, with a focus on how hydropower could be fully utilized to meet the country's long-term energy demands sustainably.

Keywords: Hydropower, Renewable Energy, Kenya, Green Energy

INTRODUCTION

Throughout the industrial revolution era, the use of fossil fuels was the main source of energy. As human development in farming and industries demanded more energy use, the global fuel demand and the pollution of the environment from greenhouse gas emissions (GHG) became unsustainable. There was an urgent need to diversify energy sources to cut on carbon emissions and renewables such as hydropower, wind and solar came in handy. Access to clean, affordable, and reliable energy became a key pillar to achieving sustainable economic growth and mitigation of climate change. The share of the world's population with access to electricity has grown from 83% in 2010 to 90% in 2019, representing a decline in the number of people lacking access to electricity from 1.2 billion to 759 million (IRENA & Development Bank, 2021). However, despite the steady growth in accessing electricity, Africa still lags behind with a population of 570 million lacking access to electricity, particularly in the rural and semi-urban areas. The rural access to electricity outpaced the population growth over the 2017-19 period indicating a positive trend. Several countries in Africa including Kenya and Uganda have kept the access pace and made the most progress in electrification with the population growth achieving annual growth in electricity access of more than three percentage points after 2010 as depicted in Fig. 1. Renewables have played a critical role in the energy transition, cost, and accessibility and account for 29% of the total global share as of 2020 and are expected to grow by more than 8% in 2021 (IEA, IRENA, UNSD, WB, 2020). The need to reduce CO_2 emissions and mitigate climate change has brought the enactment of better policies that reduce the cost of renewables and promote their adoption(R E N, 2021). Kenya ranks as one of the cleanest countries, with 85% of the grid power coming from renewables and the Net Grid Emission is estimated at 0.3322 $kgCO_2/kWh$ (Energy and Petroleum Regulatory Authority, 2019).

Lack of power has a negative impact on the adoption of new technology in a variety of fields, including agriculture, education, and finance (Blimpo & Cosgrove-Davies, 2019). Kenya is amongst the Sub-Saharan Africa (SSA) countries with the great ambition of achieving universal access to electricity with a focus on transport and industrial sectors and it has clearly set out the goals and the target year as 2022 (Alupo, 2018). Generally, Kenya ranks as the fastest-growing economy in Africa and with a higher electrification rate of 75%, according to the joint world bank report (IEA, IRENA, UNSD,WB, 2019). As a result, in order to meet rising demand, indigenous renewable energy resources must be explored as part of the search for long-term energy solutions.

The Kenyan energy sector is a mix of hydropower, geothermal energy, wind, solar, biomass and biogas (Takase et al., 2021). The government has been setting up plans and policies to accelerate the deployment of renewables in both large- and small-scale capacities. Through the enactment of the Energy Act, 2019 (GoK, 2019) and the formulation of the Feed-In Tariff (FiT) (MOE, 2012) in 2010 which were developed to attract investment and development of small and large power plants in the renewable field demonstrates the government’s dedication to promoting electricity generation from renewable energy sources. The Government intends to set up a Green Energy Fund Facility under the National Task Force on Accelerated Development of green energy with the purpose of lending funds to viable renewable energy projects at concessional rates as set out in the Climate Change Act (Republic of Kenya et al., 2015). The National Renewable Energy Development Strategy as set out in the Least Cost Power Development Plan (LCPDP) (ERC, 2018), Rural Electrification Master Plan (Ministry of Energy and Petroleum, 2016), the Kenya National Climate Change Response Strategy, and Kenya Vision 2030 (The Ministry of Planning and Devolution, 2007), reaffirms the commitment to increase the use of renewable energy one of them being small scale hydropower plants.

Hydropower plants are classified into large (above 30 MW) and small (up to 10 MW). The SHP includes mini (up to 1 MW), micro (up to 0.1 MW) and Pico (up to 0.01 MW) (John. G. Mbaka, 2017). Hydropower technologies can currently convert more than 90% of available energy into electricity, whereas thermal power plants and other related technologies have efficiency ranging from 30% to 50%. and is the most efficient technology for generating electricity, with significant advancements expected in the future, particularly in IT and automation (International Renewable Energy Agency, 2012)-(Kougias et al., 2019). In terms of achieving SDG goals, hydropower is the most inclusive renewable source of renewable energy solving four SDGs, i.e., SDGs 6,7, 9, and 13 concurrently. Hydropower has been at the centre of the water-energy-food nexus and serves as a critical pillar of Agenda 2030 and an enabler of sustainable development in the three dimensions (OFID, 2017).

In the past century, Kenya has developed hydro plants in several areas which are widely distributed across the country mainly through independent power producers (IPPs) like Kenya Tea Development Agency (KTDA) (Fern & Associates, 2005). These sites are far off from the main grid and are located in remote areas where the local people are usually engaged in agricultural activities. Small scale run-off river hydro plants have proven to be an economical and sustainable way of meeting local demand in decentralized rural areas through mini-grids

(Mwaniki et al., 2019). The Kenyan hydropower sector experiences challenges with unreliable rainfall during dry seasons which affects the total power produced. Research and studies conducted on several river schemes and old dams indicate a substantial untapped hydropower potential. Proposals have also been made to upgrade the old plants with studies indicating that rehabilitation of hydro plants is profitable and feasible due to the long life of civil works(Ministry of Energy and Petroleum, 2016).

The current study keenly evaluates the current state of renewable energy in Kenya, government policies and documents to review the trend and focus of the government in the hydro energy sector. It clearly illustrates the efforts and investments the government has made in the generation of hydropower; its economic benefits and the future steps Kenya can take to fully exploit the water resources sustainably to reach a wider economic value in the provision of clean and sustainable energy.

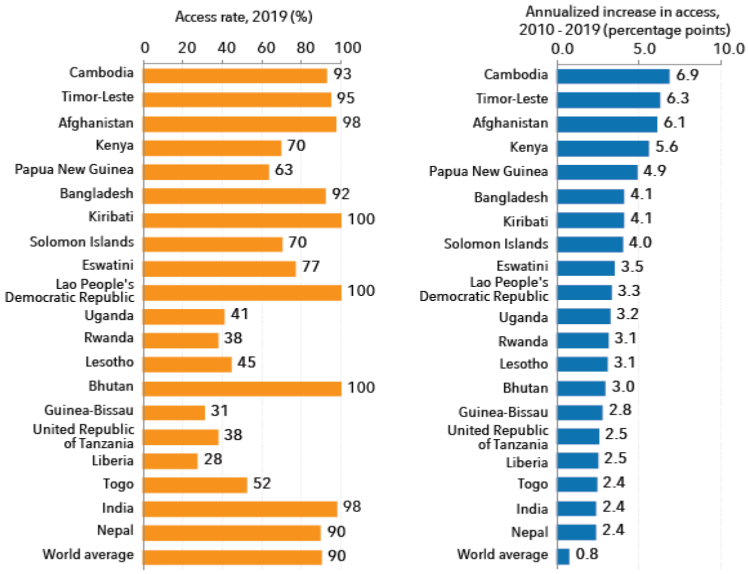

Figure 1: Electricity access in the 20 fastest-electrifying countries, 2010-19 (IRENA & Development Bank, 2021)

THE CURRENT STATE OF RENEWABLE ENERGY MIX IN KENYA

Kenya has a promising potential for renewable energy generation. With the abundance of solar, hydro, wind, biomass, and geothermal resources, the government sought to expand renewable energy generation in the country. The government has prioritized the deployment of mini-grids to meet the power demands of rural areas using the least-cost approach. Given the vast availability of renewable energy resources, integration of these different sources will help secure a stable and reliable grid for the nation. At present, the Kenyan population is served with 90% of energy from renewable resources with geothermal overtaking hydropower as the main source of grid power as shown in Table 1 (Energy and Petroleum Regulatory Authority, 2020).

The overall technical hydropower resource is estimated to be around 6 GW, with small rivers accounting for half of it. Hydro resources are located in places where the domestic energy demand is high but commercial demand is low, mainly in rural and remote areas. The nationwide potential for small, mini, and micro-hydro systems is estimated to be 3,000 MW. On the other hand, the installed grid-connected small-scale hydroelectric projects contribute only about 15.3 MW. Nonetheless, several other small hydro schemes under private and community generation are not connected to the grid, particularly in the country's tea estates.

Table 1: The distribution of power generation sources (Energy and Petroleum Regulatory Authority, 2020)

Generation Capacity of Electricity in Kenya Source (As of December 2020)	**Capacity (MW)**	**Capacity %**
Geothermal	863	30.1%
Hydropower	837	29.2%
Fossil Fuels (incl. gas, diesel and emergency power)	720	25.1%
Wind	335	11.7%
Solar	50	1.7%
Bagasse Cogeneration	28	0.97
Others	32	1.14%
Total	2865	100.0%

Wind Energy

Kenya is endowed with favourable wind speeds with 73% of the country experiencing wind speeds of 6 m/s or higher at 100 meters above ground level (Energy Regulatory Commission of Kenya, 2020). Of this 28228 sq. km experiences wind speeds of between 7.5 – 8.5 m/s and 2825 sq. km experiences wind speeds of between 8.5 – 9.5 m/s as shown in Fig. 2.

WinDForce Management Services Pvt. Ltd conducted a wind energy data analysis and development programme in 2013, estimating a total technical potential of 4,600 MW. This is around two times Kenya's current installed power capacity. Currently, the installed wind capacity stands at 436 MW with the majority of this coming from the Lake Turkana wind plant which is the largest wind power plant in Africa and 100 MW from the Kipeto wind farm. There are several other plants with huge capacities in the pipeline such as Meru wind farm (400 MW), Marsabit wind farm (300 MW) and many others as explained in the Government of Kenya plan (ERC, 2018).

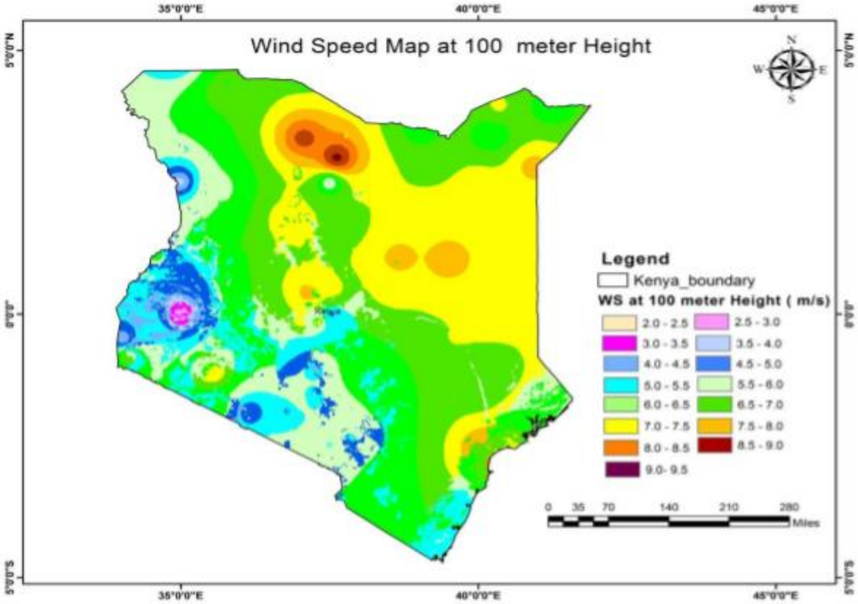

Figure 2: Wind energy potential at 100 meters above the ground (Energy Regulatory Commission of Kenya, 2020)

Solar Energy

The location of Kenya at the equator is suitable for solar energy utilization, with about 1.2% of the population homes using solar energy. The solar radiation received in Kenya is about 4-6 kWh/m^2 (Energy Regulation Commission of Kenya, 2020). Solar energy is primarily employed in the nation for photovoltaic systems used for electronic appliances and lighting. The largest grid-connected PV plant is in Garissa, with a 55 MW installed capacity. Similarly, some PV solar power plants have been set up in Kenya on both small and large capacity scales. Among the large and already commissioned plants that are connected to the grid are the 100 kWp plant at Kenyatta university, the 72 kWp at a flower farm at Uhuru Flowers, the 60 kWp Nairobi SOS Children's village plant, the 575 kWp at the UN ground in Nairobi, and a 1 MWp powerplant at a Williamson's Tea Changoi tea processing plant. Many flower farms have also adopted solar PV power systems like the 60 kWp Tambuzi Ltd.

Additionally, a good number of solar mini-grids have been set up, owned by the state or individual organizations. Among the privately owned mini-grids are the 1.4 kW and the 20-kW mini-grids by Powergen and Powerhive, respectively. On the other hand, some community-owned mini-grids are the 135 kW mini-grid by the Thiba community and the 13.5 kW facility owned by a cooperative in Kitonyoni (Pedersen, 2016). Furthermore, apart from the large and small grids, Kenya has adopted hybrid solar plants to complement other forms of energy like diesel generators and wind. The Kenyan government's rural electrification master plan, which dates back to 2008, emphasizes on upgrading existing diesel power plants with hybrid solar and wind power systems. Hybridization is essential since it improves the capacity and efficiency of a power plant by deploying a mode that is effective under any given conditions. Similarly, hybridization is a move to cut operational costs. Part of the hybrid solar power plants is shown in Table 2.

Table 2: Some solar hybrid mini-grids in Kenya (Africa & ECN, 2018)

Mini-grid	**Nominal Capacity (kW)**	**Effective Capacity (kW)**
Elwak	740	610
Habaswein	760	542
Hola	1120	660
Lodwar	2740	1480
Mandera	2350	1450
Mfangano	520	390
Takaba	244	244

Apart from electricity generation, solar energy has been utilized in water heating systems and cooling systems. With the Kenyan solar water heating regulations of 2012 (Government of Kenya, 2012), all premises with hot water exceeding 100 litres per day were mandated to install solar water-heating systems, which necessitated the adoption of solar water heaters. The heaters have replaced the heating methods that rely on electricity and biofuels that were previously common. On the other hand, on the Kenyan coast, solar cooling systems have been adopted. ISAAC PV-powered ice makers have been set up. The ice makers achieve the ammonia/water refrigeration process by entirely relying on solar power (Africa & ECN, 2018).

Geothermal Energy

Geothermal energy is abundant in Kenya, especially in the Rift valley (Africa & ECN, 2018). About 7000 MW and 10,000 MW of electricity can be generated in the Kenyan Rift Valley's central region. Suswa, Baringo, Menengai, Eburru, Korosi, Lake Bogoria Longonot, Olkaria, and Paka are among the locations that have been investigated. Surface investigation and evaluation of geothermal resources have already been carried out in several fields, including Menengai, Baringo-Silali, Suswa, Mwananyamala, Homa Hills, Barrier, and Nyambene and Chyulu Hills. Additionally, wells in the Olkaria, Menengai, and Baringo-Silali geothermal fields have been rigged, with fifty-nine geothermal producing wells successfully established. Drilling is underway in Menengai and Baringo-Silali, with a total of 51 geothermal wells rigged and about 170 MW equivalent of steam detected for power generation (Geothermal Development Company, 2021).

Biofuels and Biogas

Kenya has made attempts to exploit biofuels in the energy sector. The primary liquid biofuels that have been explored are biodiesel and bioethanol. Biodiesel may be produced from non-edibles like castor, cotton, Jatropha, rapeseeds, and sunflower. For instance, from research at Jomo Kenyatta University of Agriculture and technology, the yellow oleander plant was considered suitable for biodiesel. On the other hand, cassava, sugarcane, and sorghum are the leading edibles that have been established as good ethanol producers. Some sugar companies, therefore, are leading in ethanol production from sugarcane. As a result, certain sugar firms are at the forefront of ethanol generation from sugarcane. Figure 3 shows some of the biodiesel producing plants.

(a) Jatropha plant and seeds (b) Yellow oleander plant

Figure 3: Some of the biodiesel-producing plants

Biogas

Biogas is produced when a naturally occurring process takes place between organic wastes like compost and agricultural wastes. Municipal garbage, sisal, and coffee manufacturing have all been recognized as possible biogas sources in Kenya. The entire installed electric capacity potential of all sources ranges from 29 to 131MW, accounting for about 3.2 to 16.4% of total energy output.

CURRENT STATE AND POTENTIAL OF THE SMALL-SCALE HYDROPOWER PLANTS (SHPs) IN KENYA

SHPs are particularly well suited to produce power in mountainous rural regions with a large number of tiny perennial streams, where grid-supplied energy may be unfeasible. SHPs are classified as those hydropower plants whose generating is up to 10 MW. The SHPs span from Pico (up to 0.01 MW), micro (up to 0.1 MW), and mini (up to 1 MW). The micro and Pico SHP are typically implemented at the community level where the electricity grid connection is scarce, but the mini-SHP are typically connected to the electrical grid system (Lahimer et al., 2013). SHPs possess several advantages over large hydropower facilities, including shorter implementation periods, lower initial financial investment, and less environmental impact (Paish, 2002). Moreover, SHPs being cheaper than solar PV and their ability to be used as standalone systems or integrated systems with other renewable energy technologies make them the most viable technology. SHPs are either run-of-river types that entail diverting water from the main river using a weir or impoundment types with water storage systems. The former is more suited for small capacities and in cases where the available construction funds are minimal (Anderson et al., 2015). The magnitude and type of the SHP are dependent on the site in terms of water head, flow rate, and the level of technology. The effective cost for the SHPs ranges from 1,000 to 20,000 USD/KW. Current trends to design multipurpose SHP, whose impoundments also serve in flood control, irrigation, and power generation, hasten investment recovery and create ease of raising maintenance funds. The maintenance costs are generally lower than other power generation techniques like diesel generators, which are disadvantageous in terms of maintenance costs and their lifespan, which averages 50 years. The world's small hydropower energy clocks 1.5% of the installed capacity, 4.5% of the total installed renewable capacity, and 7.5% of the hydropower capacity below 10 MW.

Africa has a 1% share of the total installed capacity with an immense potential yet to be explored(Uria-Martinez et al., 2021). On the other hand, the eastern Africa region has a 68% of Africa's unutilized SHP potential, with Mauritius utilizing the most significant percentage of her potential. The percentage utilization of the small hydro-potential in the eastern Africa region is shown in figure 4.

The quest to attain universal access to electricity by 2022 has seen Kenya make a giant stride toward installing small hydropower plants (Renewable & Agency, 2016). SHP has been adopted in some sectors such as grid energy generation and the commercial operation of industries and facilities like tea factories and hospitals. Kenya boasts 16% of the installed capacity of SHPs in the Eastern Africa region (UNIDO, 2019). The ownership of such facilities ranges from the state, communities, and manufacturing plants. For instance, after the resumption of construction of SHPs in the 1990s, most privately owned tea processing companies have installed SHPs to reduce running costs by minimizing overreliance on diesel backup generators used during power outages. Some of the organizations with installed SHPs are shown in Table 3.

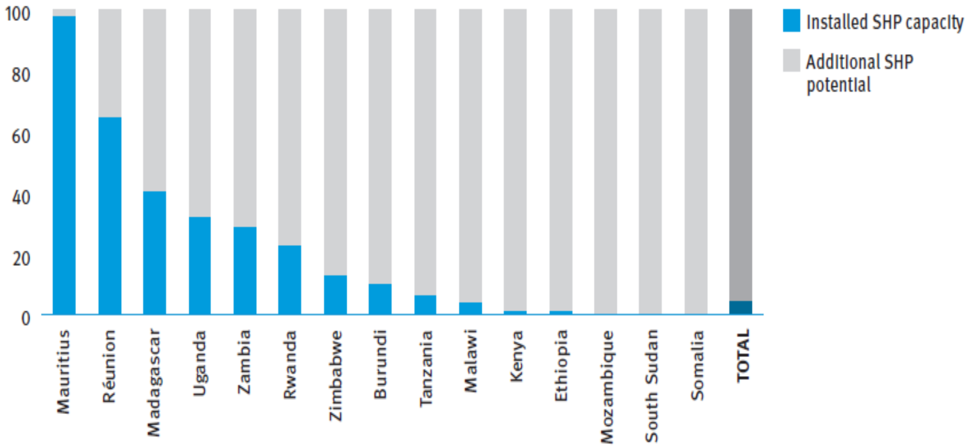

Figure 4: Percentage of utilized small hydropower potential by country in eastern Africa (UNIDO, 2019).

Table 3: Some of the installed SHPs in Kenya since 1990 (UNIDO, 2019)

Plant	Year	Ownership	River	Installed Capacity (MW)
Diguna	1997	Missionary	N/A	0.4
Tenwek	-	Missionary	N/A	0.32
Mujwa	-	Missionary	N/A	0.01
CommunityMHPs	2002	-	N/A	0.02
Tungu kabiru	2000	Community	Tungu	0.01
Thima	2001	Community	Mungeria	0.01
Kathamba	2001	Community	Kathamba	0.001
Imenti	2009	KTDA	Imenti	0.9
Gikira	2016	Community	Gikira	0.514
Gura	2017	KTDA	Gura	5.8
Kiawambogo	2019	Magiro Power	-	0.18
Kahinduini	2019	Magiro power	-	0.26

Currently, the Kenyan government promotes small hydropower through the Ministry of Energy, which gathers hydrological data regularly, conducts pre-feasibility and feasibility assessments of feasible locations, and disseminates small hydropower information. Furthermore, the ministry educates investors and consumers on the economic possibilities of SHP as an alternative energy source. In addition, to promote SHPs, the Ministry is establishing community-based pilot programs in viable regions. A FiT policy was created in 2008 (and amended in January 2010) to encourage investment and development of small and micro hydropower projects (Feed-in-Tariffs Policy on Wind, Biomass, Small Hydro, Geothermal, Biogas and Solar Resource Generated Electricity, 2012). Regardless of the government's efforts to promote SHPs, their implementation encounters several obstacles. The major problem is a lack of finances to carry out the initiatives. In addition, low research levels have resulted in the scarcity of data, lack of technological know-how in the local scene, and scarcity of competent personnel. In some cases, limited knowledge may lead to the cold reception of the SHP from the locals. Furthermore, the unpredictable nature of the rainfalls poses a significant challenge to the development of SHPs. For example, the Tana River's inflow rate has been substantially decreased due to reduced rainfall in Kenya's central area (Feed-in-Tariffs Policy on Wind, Biomass, Small Hydro, Geothermal, Biogas and Solar Resource Generated Electricity, 2012). The flow of permanent rivers has been further hindered by widespread deforestation caused by the high demands for firewood, charcoal, and logging.

While Kenya's SHP development potential (up to 10 MW) was projected to be 3,000 MW, as of 2019, the installed capacity was just 39.4 MW. The utilization level of Kenya’s potential is somewhat lower in comparison to other eastern African countries as shown in Fig.5.

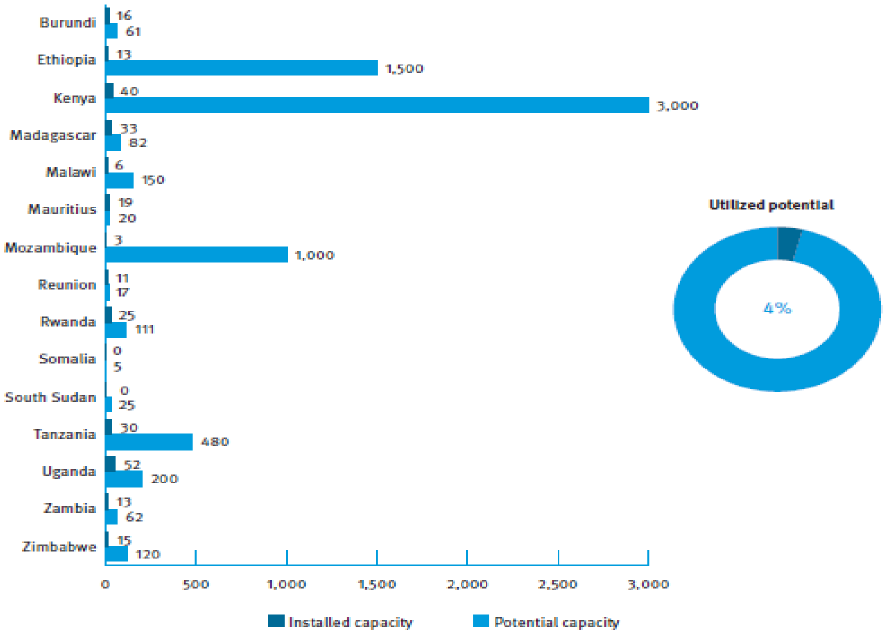

Figure 5: Installed and potential capacity in eastern africa for SHP up to 10 MW [10].

Several rivers that can potentially host stand-alone SHPs have been found through investigation. The river's potential spans from 50 kW to 700 kW and alternative sites are being investigated. Among the rivers are the Athi, Tana, and Ewaso Ngiro. Since these locations are populous regions, the potential for SHP is significant (Kiplagat et al., 2011).

CURRENT STATE AND POTENTIAL OF THE LARGE-SCALE HYDROPOWER PLANTS IN KENYA

Most of Kenya's power is generated by hydropower, accounting for at least 677 MW of installed capacity. The theoretically viable hydropower potential of the nation is over 3,500 MW, although only about a fourth of that has been exploited. Out of the 3,500 MW, large hydropower prospects account for about 1500 MW, out of which 1,310 MW are viable for plants with a capacity of at least 30 MW. The distribution of the identified capacity is as follows: there are 434 MW in the Lake Victoria basin, 264 MW in the Rift Valley basin, 109 MW in the Athi River basin, 604 MW in the Tana River basin, and 146 MW in the Ewaso Ngiro North River basin (Mokveld & Eije, 2018). Various companies like KenGen have installed various large hydro projects. Some of the installed plants include Masinga, Kamburu, Gitaru, Kindaruma, Kiambere, Tana, Turkwel, Sondu Miriu, and Sang’oro, with capacities as indicated in Table 4.

Table 4: Some of the large hydropower stations in Kenya (Energypedia, 2020).

Hydropower Station	Commissioned Year	Capacity (MW)
Gitaru	1999	225
Kiambere	1988	165
Kindaruma	1968	72
Masinga	1981	40
Kamburu	1974	93
Sang’oro	2013	21.2
Sondu Miriu	2007	60
Turkwel	1991	106

The Future of Hydropower in Kenya

The global overview of hydropower as a highly reliable energy source that can be dispatched easily to meet the market demand makes it a future focus on research and development. Hydropower is regarded as the nation's ‘big battery’, storing power in the form of water. Energy from rivers now accounts for one-fifth of global electricity output, and it is expected to grow in the future. While wind and solar power are becoming more popular, the cost of hydropower generation remains low, giving it the indisputable renewable energy future. The growth of technology innovation and integration of energy systems to create stable and reliable grids has driven the hydropower sector research and development, especially on the electro-mechanical equipment used. The Kenyan government is committed to accelerating the use of renewable energy, with clear and specific goals like the vision 2030 which aims to transform Kenya into a newly industrializing, middle-income country providing a high-quality life to all its citizens. At the top of this vision, the energy factor is mentioned as the leading enabler to achieving vision 2030. The Kenyan government has been on the trajectory of formulating and revising energy policies to meet the current market demands. Through the updated least-cost power development plan 2017-2037, the government has studied the energy market demand, transmission, and energy expansion and outlined the steps to achieve this. While the government is focused on building the economy based on renewables, there is a big concern about the intermittency of renewable energy sources like wind and solar. Hydropower is presented as a solution to meet this variable energy. Several new projects and refurbishment and upgrading of the old plants have been put up to increase the energy generation from hydropower. The sections below highlight what the government is currently doing, what it has planned, and what needs to be included for a more sustainable and secure grid.

Run-Off River, Small and Large Hydropower Plants

Damless hydropower plants, also known as run-off river hydropower plants, generate electricity by utilizing the natural flow rate of water rather than building large reservoirs. These plants have a lower ecological impact than conventional dams because they do not require a reservoir or alteration of the flow of the river. However, damless hydropower plants generate less total power than traditional hydropower plants. Damless plants' energy production is unpredictably variable due to river flow rate, season, and year-to-year change. The Kenyan River basin supports plenty of run-off river power schemes and many have been constructed to meet local community energy demands and to some point small industrial operations in the rural areas.

The formulation of the FiT policy has attracted investors to pump finances into setting up small power plants. KTDA has been on the leading front to supply power to its numerous tea factories spread across the country. This sector of small hydropower remains largely unexploited due to the lack of enough data to support investments in such sectors. The government is however keen on closing this gap by conducting studies on the rivers spread across the country to provide reliable and accurate data that can guide investors to venture into this sector with confidence. Several policies that favour the generation of power from renewable sources like hydropower will be essential in promoting investments in this sector.

In the government, long term goals of meeting the energy demands for the vision 2030, small and large hydropower plants have been included in the energy mix. The total installed energy capacity is expected to grow to 7213.88 MW in 2030 from 2234.83 MW in 2017. Hydropower is poised to grow from 807 MW in 2017 to 1522 MW in 2030 with heavy investment in large hydropower plants. This is reflected by current plans to develop large hydro projects in Karura and High Grand Falls, Nandi Forest and Magwagwa, and Arror. This development could lead to an additional hydropower capacity of over 800 MW in the long term (ERC, 2018).

Pumped Storage Hydropower

Pumped storage hydropower is one of the most mature, reliable, and versatile large-scale options for grid flexibility and security, promoting intermittent renewables in a cost-effective, safe, and sustainable manner, among storage technologies. Indeed, over the next decade, pumped storage hydropower has the potential to be the most cost-effective green storage solution at scale. Pumped storage hydropower (PSH), dubbed "the world's water battery," excellently complements modern clean energy systems because it can manage the intermittency and seasonality of variable renewables like wind and solar electricity. Currently, there is no single operation of a pumped hydropower plant in Kenya. However, the government advertised in 2017 inviting bids from consultants to assess the potential for optimizing large hydropower plants and developing pumped storage(Swabu & Bakabsha, 2018). The major hydropower plants include Gitaru (225 MW), Kiambere (168 MW), Turkwel (106 MW), Kamburu (94 MW), Kindaruma (72 MW) and Sondu-Miriu (60 MW). On the other hand, Australian National University (ANU) map for global pumped hydropower generated using Geographical Information Systems (GIS) shows the great potential of Kenyan rivers for developing pumped hydropower (*NationalMap*, n.d.). However, none of the sites mentioned in this study has undergone geological, hydrological, environmental, heritage, or other assessments, and it's unclear whether any of them would be acceptable. The viability of exploiting these areas on a commercial scale is unknown. For safety and efficacy, as with any significant engineering project, meticulous quality assurance will be required.

Hybridization of Hydropower Plants with Floating Solar Panels

Hybridization of hydropower plants with solar is seriously being considered in Kenya and a contract was awarded to Multiconsult to conduct studies on Kamburu, Kiambere and Turkwell hydroelectric dam basins on the integration of floating solar panels with the existing infrastructure (Power, 2020). These dams are amongst the largest ones in Kenya and the huge reservoirs can be utilized to install solar panels given the abundance of solar energy in these areas which means solar can be used to meet daytime demand when the sun is abundant, and hydropower during peak times in the evening. The coupling of hydroelectric power and solar systems is appropriate due to the negative correlation between solar and rainfall data. Hybridization of hydroelectric dams with floating solar power plants allows for more efficient and cost-effective electricity and water management, and the energy generated reduces reliance on traditional power plants and oil/coal-fired facilities, lowering carbon emissions (Bartle & Vivo, 2021). Due to the changing climate which affects water inflow in dams, hybrid hydropower with floating panels could offset the loss of electricity production as a result of reduced water levels. Furthermore, hybrid hydropower with floating solar panels could reduce water evaporation and save money on grid integration by using the same grid connection (Gonzalez Sanchez et al., 2021). The full potential for integration of floating solar panels with the existing dams is not yet established, but the government is keen to conduct feasibility studies to determine the impact of hybridization on the grid and environment.

Water-Energy-Food nexus Approach

In recent years, the water-energy-food (WEF) nexus, or the complex web of interdependencies between water, energy, and food systems, has emerged as a major concern in the overlapping scientific disciplines of sustainable development and climate change adaptation. Kenya's government has previously adopted several policies and measures that address nexus issues, but not explicitly. These include components of Vision 2030, the Green Economy Strategy and Implementation Plan, the National Climate Change Action Plan, and water, energy, and food-related policies and initiatives (Wakeford, 2017).

The construction of the Thwake multipurpose dam is an example of how the government is focusing on achieving sustainability through the water-energy-food nexus approach (China daily, 2021). The Thwake dam will provide clean water for drinking, and irrigation and generate hydropower at an installed capacity of 20MW. The successful completion and operation of this multipurpose dam will go a long way to provide more data for future planning.

Digitalization of Hydro Plants

The digitization of hydropower plants is transforming how they are operated and maintained. According to the International Hydropower Association (IHA), by 2030, more than half of the world's hydropower plants will need to be upgraded or renovated (International Hydropower Association, 2021). Improved digital controls in the hydropower sector are part of a growing trend to improve the performance of turbines, plants, and equipment by lowering costs and optimizing asset management. Manufacturers of equipment are embracing digitization as a means of expanding their service offerings. They believe that digital control systems and software can help improve decision-making and help hydro operations work more efficiently with other renewable technologies.

Kenya's hydropower plants were built a long time ago and their rehabilitation and upgrading offer a perfect opportunity to digitize the plant equipment. Rehabilitation and digitization involve enhancing overall efficiency and, thus, the amount of energy produced in addition to extending lifespan and resolving cyber-security issues. According to current estimates, digitalizing the world's 1225 GW installed hydropower capacity may boost yearly production by 42 TWh, resulting in annual operating savings of USD 5 billion and a considerable reduction in greenhouse gas emissions (Kougias et al., 2019).

Digitalization will be of the essence in harvesting huge performance data around hydropower plants and allow the identification of deviations in the parameters of the plants given the fluctuation of water levels with seasons in Kenya (International Hydropower Association, 2021). Accurate capture and analysis of the collected data will be critical in helping planners forecast future performance and design better-integrated energy systems with other variable renewable energy technologies like solar and wind. As the Kenyan government embarks on rehabilitation of the old plants, digitalization should be a focus to maximize generating power capacity from these operating hydro plants. A national-scale feasibility analysis should be conducted to determine the cost and the benefits of modernizing equipment and switching to digital operation

Assessment of Hydropower Potential in Existing Infrastructure

Small dams developed in rural-agricultural settings for purposes other than energy generation, such as irrigation, drinking water supply, and flood mitigation, have hydro potential that has yet to be exploited. (Patsialis et al., 2016). Dam construction and associated civil works can account for up to 60% of the capital cost of new hydro (Samora et al., 2016). As a result, when feasible, converting such dams to hydroelectric facilities usually costs and takes less time. The first large-scale assessment of such potential was carried out in the United States, with the analysis revealing that the conversion of non-powered dams (NPDs) in the US could provide up to 12GW of hydropower capacity (Hadjerioua et al., 2013). A similar analysis estimated the potential in NPDs of sub-Saharan African states to be at 243.5MW. In Kenya, no similar analysis has been conducted to identify the potential NPDs and this limits the investments in such areas. Given that majority of the Kenyan irrigation and drinking water projects are mainly located in the rural and less populated areas, conversion of such projects to generate power will be less costly and will revolutionize the rural economic activities.

CONCLUSION

Access to electricity is a pressing issue in Kenya, especially in the rural areas that are far away from the grid. While Kenya boasts of an electrification rate of 75% a lot needs to be done to attain universal access to electricity. To attain this requires heavy investment in the energy sector to provide access to electricity that is clean, affordable and reliable**.** Energy production in Kenya is experiencing a steady transition from fossil fuels to renewables. Great progress has been made in the formulation of policies that promote the adoption and use of renewables. However, the expansion of hydropower slowed down in the last decade due to the lack of better policies that will attract investors. This study presents the current state of renewables in Kenya while focusing on hydropower. It reviews sector policies and documents in place to articulate possible solutions on how Kenya can maximize her waters to generate power.

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