Review Article

East Africa's Renewable Energy Diversity Landscape: A case of Kenya's Potential, Progress and Future Prospects

ABSTRACT

Despite the region's enormous renewable energy resources such as solar, wind, geothermal, and hydroelectric power, there remains a significant gap in harnessing these resources successfully to meet the rising energy demands and mitigate climate change effects. Therefore, there is need address the critical need to understand and evaluate the renewable energy landscape in East Africa, with a particular focus on Kenya. This study aims to evaluate the unrealized potential, examine the country's present renewable energy infrastructure, chart its growth trajectory, and suggest future paths for the country's sustainable energy development. Geothermal energy constitutes 28.8% of Kenya's total installed capacity, while hydro, wind, solar, and bio-energy collectively contribute 25.5%, 13.3%, 7.4%, and 0.1% respectively, comprising about 75% of total generation. Currently, hydro, geothermal, wind, solar, and bioenergy are utilized at rates of 10.7%, 9.4%, 7.3%, 1.6%, and 1.5%, respectively, demonstrating a considerable underutilization of their capacity. Kenya currently generates 2453.9 MW of renewable energy, with ongoing projects poised to raise this capacity to 3982.9 MW, inclusive of those under development. By 2032, the Kenyan government aims to install 350–450 MW of power generation and 150–250 MW of electrolyzer capacity to substitute 50% (300,000–400,000 tonnes per year) of nitrogen fertilizer imports. In conclusion, the investigation of the diversity of renewable energy sources in East Africa, especially in Kenya, discloses significant potential and promise for future prospects. The review highlights the worth of investment opportunities to create strategic partnerships and improve infrastructure, research, and capacity building. It also points out that investor cooperation is essential to closing the capacity-to-use gap and advancing a strong, sustainable future for both East Africa and the rest of the world.

Keywords: East Africa, Renewable Energy, Potential, sustainable

1. Introduction

Despite the region's enormous renewable energy resources [1, 2] such as solar, wind [3, 4], geothermal, and hydroelectric power, there remains a significant gap in harnessing these resources successfully to meet the rising energy demands and mitigate climate change effects [1, 5]. This suggest that these resources have not made as much progress as they could have over the previous few decades in any one area of their growth. This review purposes to address the vital need to understand and evaluate Kenya's renewable energy landscape, focusing on its diversity, potential, progress, and future prospects within the wider East African context. Additionally, it presents a promising opportunity for investors to engage with and support the ongoing growth and development of renewable energy in this dynamic market. In addition to shedding light on the diverse possibilities of Kenya's renewable energy market in order to promote fair and sustainable energy growth throughout East Africa.

Globally, a growing number of nations are giving priority to renewable energy sources in an effort to reduce greenhouse gas emissions and lessen the thinning of the ozone layer. This trend has been sparked by the rising costs of fossil fuels and their harm to human welfare [6]. In addition, the momentum comes from global accords such as the Kyoto Agreement, which outline national obligations for environmental protection. This also due to the Kyoto Agreement and the responsibilities that each nation has under it for the preservation of the environment [7]. By increasing the amount of electricity generated from renewable sources and decreasing the amount of energy derived from fossil fuels, it is possible to decarbonize the energy sector and lessen the effects of climate change [8]. By the end of 2018, there were a significant 2,351 GW of renewable energy generated worldwide [9, 10]. With 1,172 GW of installed capacity, hydropower is by far the largest provider. With capabilities of 564 GW and 480 GW, respectively, wind and solar energy make up the majority of the remaining half. Additional renewable energy sources include of 500 MW of marine energy, which includes tide, wave, and ocean energy, 13 GW of geothermal energy, and 121 GW of bioenergy. Investments in renewable power and fuels demonstrated continuous growth for the fourth consecutive year, reaching an impressive USD 366 billion. A remarkable surge in global electricity generation resulted in solar and wind power jointly surpassing 10% of the world's electricity production for the first time. Encouragingly, there were substantial market recoveries for solar thermal and biofuels, following declines in 2020, contributing to a more positive outlook for renewables in heating and transportation. The period from 2011 to 2021 witnessed a substantial increase in renewable energy's contribution to global electricity supply, rising from 20% to 28%. Conversely, fossil energy decreased from 68% to 62%, and nuclear energy declined from 12% to 10%. The share of hydropower experienced a slight reduction from 16% to 15%, while solar and wind power collectively surged from 2% to 10%. Biomass and geothermal energy also exhibited growth, increasing from 2% to 3%. Globally, there are now 3,146 gigawatts of renewable energy capacity installed across 135 countries, and 156 countries have enacted laws to regulate the renewable energy sector [11, 12]. Numerous nations have already achieved impressive milestones, with renewable energy contributing more than 20% of their total energy supply, and some surpassing the remarkable feat of generating over half of their electricity from renewable sources. For successful CO_2 emissions mitigation and well-informed policy formation, it is imperative to leverage insights into Kenya's large renewable energy contribution.

As of 2023, Kenya generated around 3078 MW of total power, with an effective linked capacity of 2925 MW. However, there is now a nearly 1,000 MW difference between the nation's peak power demand and its overall electricity producing capacity, according to EPRA. With an installed capacity of 3,074.34 MW in 2022 and an average peak consumption of 2057 MW of which solar PV contributes 2.47% [13, 14]. Furthermore, the installed renewable energy capacity reached 2,984 MW, with a peak demand of 1,994 MW in 2021. Comparing these numbers to those from 2010, when installed capacity was 1,473 MW and peak demand was 1,068 MW, one can see a significant increase [15, 16]. Additionally, non-RE sources originating from thermal sources, mainly fossil fuels, are anticipated to contribute 810.52 MW [17] generating roughly 0.566 tons of carbon dioxide per megawatt-hour (tCO_2/MWh)[18]. According to 2019 research, Kenya's power generation plan has a capacity of 2,929 MW, of which 2,178 MW (or 74% of total capacity) comes from RE, demonstrating the power of this source in mitigating climatic and environmental concerns [19]. It is also believed that renewable sources is said to accounts for about 90 percent of the electricity capacity in the country with the aim of lifting this to 100% by 2050 [20].

Many East African nations, including South Sudan (SS) have not harnessed their wealth of renewable energy resources, which include biomass, solar, wind, and hydropower. Country like SS at the moment, primarily dependent on fossil fuels, which means that just 7.75% of people have access to electricity [21]. The country has an installed generation capacity of just 221.5 MW, which signifies less than the demand of over 300 MW. this indicate that a large portion of this capacity is either non-operational or devoted to the oil fields of the nation, leaving less than 70 MW available to the general people. To make matters worse, over half of this capacity is centered in Juba. **Table 1** presents an overview of the East Africa energy sector, highlighting the untapped resources within the region.

Table 1: An Overview of East Africa energy sector

No			Kenya	Uganda	Tanzania	Burundi	Rwanda	South Sudan
1	Hydro power	Status	838.5	1,072.90	581	35.2	104.6	42
		Potential	7812	2200	4700	1700	672	5,583
2	Wind	Status	436.1	-	2	-	-	-
		Potential	6,000	-	-	-	-	19,757.8
3	Solar	Status	212.6	60.93	2	7.5	12.1	32
		Potential	15000	5000	-	-	-	-
4	Geothermal	Status	940	-	200	-	50	-
		Potential	10000	450	650	18	170	-
5	Bioenergy	Status	2	111.743	63	4	-	-
		Potential	131	1650	-	-	-	-
	Total renewable		**2429.2**	**1245.5**	**848**	**46.7**	**166.7**	**74**
6	Non-Renewable		810.52	101.08	1171	30.5	58.8	147.5
	Total		**3239.72**	**1346.58**	**2019**	**77.2**	**225.5**	**221.5**
7	Electricity Access (%) [22]		76.54	45.2	37.7	10.2	48.7	7.75

Kenya stands out among the cited nations for its wide spectrum of RE, which sets it apart from the others, despite having a high installed capacity in East Africa [23]. According to the data, there is a lot of room for investment, especially in the fields of hydro, wind, solar, geothermal, and biofuels [24]. Moreover, Kenya has a more electricity-accessible population than its neighbors, which highlights the significance of transparency for prospective investors looking to fund sustainable development projects in the area. Furthermore, future energy consumption is anticipated to rise due to the rapid population development, as will housing, health, and education needs as well as the possibility for undiscovered minerals [17]. A study by Mudany [16] showed that Kenya's electricity price is notably high at US$ 0.22 per kilowatt-hour (kWh), contrasting with Tanzania's lower rate of US$ 0.098 per kWh and Uganda's rate of US$ 0.133 per kWh. This discrepancy emphasizes how crucial it is to continue analyzing and addressing the variables influencing Kenya's energy prices in order to improve affordability and promote regional economic competitiveness [25].

With a primary focus on Kenya, this review probes into the intricate landscape of renewable energy variety in East Africa. We seek to untie the complex dynamics underlying the energy shift in the region by evaluating Kenya's potential, scrutinizing its growth, and examining its future prospects. This study purposes to provide important insights into the opportunities influencing Kenya's renewable energy trajectory and further deepen the understanding of the changing dynamics of renewable energy distribution and investment prospects in East Africa and beyond by placing Kenya's experiences within regional and global frameworks.

2. Current RE status in Kenya

Kenya's journey in renewable energy appears as a convincing story of potential and success amidst rising environmental concerns and the urgent demand for sustainable energy solutions. The following sections outline the current state of development, potential, future outlook, and investment opportunities for renewable energy in Kenya.

2.1 Solar energy

Solar energy is radiant light and heat from the sun harnessed using different forms of technologies such as solar photovoltaic, solar thermal energy, solar heating and solar architecture. In recent years, the Kenyan government, led by the Ministry of Energy, has significantly increased investments in the solar industry, particularly focusing on electrifying rural schools and health facilities through solar systems, including the distribution of solar-powered laptops to primary schools [26, 27]. Additionally, various industry players have introduced tailored solar solutions such as home systems, lanterns, refrigerators, and air conditioners to address the energy needs of rural populations [28], while efforts to retrofit diesel-powered mini-grids with solar hybrids and establish new solar mini-grids in remote areas are underway.

Kenya receives daily average irradiance of 4-6 kWh/m^2/day with Eldoret receiving about 5.58 kWh/m^2/day. The overall solar potential in Kenya is estimated to be around 15 GW. However, solar energy barely makes up 2.4% of the Kenya's energy supply at the moment [13]. According to research done in Kenya, the dispersion and conversion efficiency of solar photovoltaic (PV) modules allow for the conversion of roughly 10 to 14% of solar energy into electrical power. This could result in an annual energy generation of approximately 23,046 TWh/year for PV installations, demonstrating Kenya's ability to meet all of its electricity needs through solar resources [29]. Currently installed and under development solar energy capacity in Kenya totals 372.6 megawatts (MW) with the largest installation being Garissa Solar with 55MW installed capacity. The 400-acre private farm in Mogotio that houses the approximately 150,000 solar panels that make up the Nakuru Solar Park is seen in Figure 1.

Table 2 shows the solar power plants in Kenya.

Table 2: Commissioned Solar power projects in Kenya

S/N	**Plant**	**Capacity (MW)**	**Year commissioned**	**County**
1.	Garissa	55	2018	Garissa
2.	Radiat	40	2019	Uasin-Gishu
3.	Eldosol	40	2019	Uasin-Gishu
4.	Alten	55	2022	Eldoret
5.	Strathmore University	0.6	2014	Nairobi
6.	Malindi	52	2022	Kilifi
Total installed		***242.6***		
7.	Kopere [30]	50	Under construction	Nandi
8.	WITU	40	Under development	Lamu
9.	Migotiyo	40	Under development	Nakuru
Total under development		***130***		
Projected Total		**372.6**		

Considering the Alten solar facility, which has 928 single-axis trackers attached to 103,936 solar panels in total. By enabling the panels to line up with the sun's rays, these trackers raise the solar

array's total productivity. As a result, the plant is expected to have a 123,000 MWh yearly capacity. On the other hand, as a ground-mounted solar project covering 651 acres with 157,000 modules, the Malindi Solar PV Park offsets 44,500 tons of carbon dioxide emissions annually and produces enough clean energy to power 250,000 households. Furthermore, Strathmore University installed 600 kW Solar PV Energy System making monetary savings on electricity bill of approximately Kshs. 2 million per month [25, 31, 32]. This highlights the investment potential in solar power plants, component manufacturing, and energy-saving solutions. It also highlights the advantages of solar energy's cost-effectiveness and environmental friendliness, as well as the need of comprehending both short- and long-term system operations and capacity expansion planning in Kenya.
In addition, the government has approved expression of interests of more than 35 projects under the Feed-in-Tariff with more than six [33] projects under construction.

Figure 1: Migotiyo Solar Project located at Kampi Ya Moto, Nakuru

2.2 Wind energy

With an estimated 346 W/m2 of wind power potential, Kenya is among the most potential African countries. It can theoretically meet all of its electricity needs because of its above-average land wind speed range of 3.26-8.11 m/s, which exceeds the average land wind speed of 3.28 m/s globally at ten meters above ground [34]. The country boasts an approximate 90,000 square kilometers area with favorable wind speeds averaging 6 m/s and above, making it conducive for wind power generation [29]. A comprehensive wind energy data analysis and development program conducted in 2013 by WinDForce Management Services Pvt. Ltd revealed a total technical potential of 4,600 MW for wind power in Kenya [35]. Projections indicate that 2,036 MW of this potential is expected to be installed by the year 2030.
The nation enjoys fortunate wind conditions, with 73% of the country experiencing wind speeds of 6 m/s or more at 100 meters above sea level, including portions of the counties of Marsabit, Kajiado, Laikipia, Meru, Nyandarua, Kilifi, Lamu, Isiolo, Turkana, Samburu, Uasin Gishu, Narok, and Kiambu**.** Gust speeds over 8.5 m/s are classified as Class I winds, while Class II winds fall between 7.5 and 8.5 m/s, Class III winds fall between 6.5 and 7.5 m/s, and Class IV winds fall between 6 and 6.5 m/s [36]. These possible speeds were noted for several heights, including 100

m, 80 m, and 60 m. This comprises 28228 square kilometers with winds between 7.5 and 8.5 m/s and 2825 square kilometers with winds between 8.5 and 9.5 m/s for heights of 100 m above the ground.

The Lake Turkana Wind Farm, which has 365 wind turbines, each with a capacity of 850kW per unit. The installed wind energy capacity was 336.05MW by 2022 [37], with the Lake Turkana Wind Plant, with 310 MW, and a 25.5 MW wind farm in the Ngong Hills providing the majority of the generation. Over the course of its anticipated 25-year operational life, the Turkana wind energy facility will be able to generate 1,400 GWh of electricity and offset 16 million tonnes of CO_2 emissions each year. Kenya's wind potential areas with different wind speeds are shown in Table 2**.** Marsabit exhibits the greatest potential for wind energy, boasting the highest wind speed at 9.27 m/s and covering a substantial area of 75,596 km^2. Following closely is Turkana, with an area of 61,353 km^2 [38, 39]. The combined estimated potential areas in fourteen counties including surpass 371,516 km^2. In **Table 3**, the current installed capacity is documented as 435.5 MW, with an additional 361 MW under development, foreseeing a total capacity of 796.5MW in the near future.

Table 3: Commissioned and under development wind power projects

S/N	**Plant**	**Capacity (MW)**	**Year commissioned**	**County**
1	Ngong wind	25.5	1993	Kajiado
2	Turkana wind Power	310	2019	Marsabit
3	Kipeto Wind	100	2020	Kajiado
	Sub Total	***435.5***		
Wind power projects under development				
4	Ngong Wind farm III	11	2021	Kajiado
5	Chania Green	50	2021	Kajiado
5	Meru (Isiolo) wind farm	100	2023	Meru
6	Ol-Ndanyat Power	10	2023	Kajiado
8	Aperture Green power	50	2024	Kiambu
9	Prunus	50	2023	Ngong, Kajiado
10	Baharini Wind Farm	90	2020 (Expected)	Lamu
	Sub Total	***361***		
	Total	**796.5**		

Despite its significant wind energy potential, Kenya currently only derives approximately 16 percent of its total electrical power from wind sources. This stark contrast between potential and actual contribution underscores the urgent need for focused research in the field of wind energy in the country [40]. The research should aim to identify and address barriers such as infrastructure limitations, policy gaps, and technological constraints hindering the widespread adoption of wind power. By exploring innovative solutions, advancements in wind turbine technology, and the implementation of supportive policies, research outcomes can inform policymakers and stakeholders, facilitating informed decisions that promote the sustainable growth of the wind energy sector in Kenya and contribute to the overall enhancement of the national energy landscape. This research provides valuable insights into the country's capacity for harnessing wind energy, highlighting specific regions where development efforts could be strategically focused for sustainable and efficient power generation.

2.3 Geothermal Energy

Kenya has 891.8 MW of installed geothermal capacity as of 2019, with the majority of the capacity located in the Rift Valley. There are 14 potential locations for the region's geothermal resources, which are believed to be between 7,000 and 10,000 MW in size [41]. Geothermal has numerous advantages over other sources of power: it is not affected by drought and climatic variability; has the highest availability (capacity factor) at over 95 %; is green energy with no adverse effects on the environment; and is indigenous and readily available in Kenya, unlike most thermal energy that relies on imported fuel. This makes geothermal a very suitable source for base-load electricity generation in the country. Geothermal energy alone is predicted to reduce GHGs by 14 metric tons of carbon dioxide equivalent (MtCO2e)[20]. Table 4 presents the Kenya's geothermal installed capacities' which is estimated at 1496 MW.

Table 4 : Geothermal plants in Kenya (installed and expected)[31]

Station	Licensee	Installed capacity	Status
Olkaria I	KenGen	185	Generation and Production drilling
Olkaria II	KenGen	105	Generation & production drilling
Olkaria III	Orpower 4	136	Generation & production drilling
Olkaria IV	KenGen	140	Generation & production drilling
Olkaria V	KenGen	170	Generation & production drilling
Olkaria IV	KenGen	140	Surface exploration & production drilling
Modular Units	KenGen	85	Generation & production drilling
Suswa	CYRQ	330	Surface exploration & production drilling
Eburu	Kengen	25	Generation & piloted generation
Akira	AGIL	70	Exploration and surface studies
Oserian	ODGL	5	Production under steam sale
Menengai	GDC	105	Production and exploration drilling
Total		***1496***	

Until now, geothermal resource surface exploration and assessment has been undertaken in a number of fields including; Menengai, Baringo-Silali, Suswa, Mwananyamala, Homa Hills, Barrier, Nyambene Hills and Chyulu hills. Further to this, Olkaria, Menengai and Baringo-Silali wells have been drilled with fifty-nine (59) geothermal production wells successfully developed in Olkaria geothermal field (see Table 6). Drilling at Menengai and Baringo-Silali is in progress with a cumulative of fifty-one (51) geothermal wells drilled and approximately 170 MW equivalent of steam already identified for power generation. The potential of the identified fields identified and undeveloped are estimated to be about 10,000 MW [29] . It is critical to review the current development state of specified fields and to conduct a thorough assessment of their potential for the fields. Stakeholders may decide wisely about how to allocate resources, invest, and formulate policies thanks to this comprehensive understanding. Organizations and governments may efficiently prioritize projects, maximize resource usage, and promote sustainable growth in certain sectors by carefully analyzing the potential and problems linked with each field. Gaining knowledge about the state of growth also makes it easier to spot gaps, roadblocks, and opportunities for improvement. This makes it easier to put customized interventions and strategies into place to help these fields reach their full potential.

2.3 Hydro power

Hydropower, or hydroelectric power, is a renewable source of energy that generates power by using a dam or diversion structure to alter the natural flow of a river or other body of water. Hydropower relies on the endless; constantly recharging system of the water cycle to produce electricity, using a fuel-water-that is not reduced or eliminated in the process. Hydropower is categorized into; large hydropower plants as facilities that have a capacity of more than 30 megawatts (MW), a small hydropower plant [42] is one that can produce up to 10 MW of electricity. The pico (up to 0.01 MW), micro (up to 0.1 MW), and mini (up to 1 MW) hydro-power plants are included in the SHP. While the mini-SHP normally connects to the grid's electrical system, the micro and pico SHP are typically utilized by communities to provide energy in places lacking power connections[43]. The estimated total hydropower technical resource in Kenya is 7,812.70 MW, with half of this attributed to small rivers. The current installed hydro capacity is 833.8 MW [17], constituting approximately 30% of the country's generation mix. The installed total capacity of small hydropower schemes as of 2019 was 11.7 MW, whilst the capacity of schemes operated by commercial developers was 8.3 MW [29]. The key identified locations with hydro energy potential, and economic significance in five locations has an estimated potential of 1,484 MW [29]. Large hydropower capacity is at 826.23 MW, while the untapped small hydro potential is estimated at about 3,000 MW, with less than 60 MW exploited and only 53.651 MW *(*See **Table 5**) supplying the grid.

Kenya's Least Cost Power Development Plan has pinpointed several potential hydro power sites for effective development. While these sites may not have been deemed economically viable in the past, recent increases in oil prices have rendered them attractive for investment. Among the most promising undeveloped hydro power sites is Mutonga on the Tana River, boasting an anticipated capacity of 60 MW and an annual average electricity generation of 336 GWh. The estimated construction cost for Mutonga is US$ 270 million. Additionally, downstream from the Mutonga site lies the Lower Grand Falls, with a capacity of 140 MW and an annual average electricity generation of 715 GWh.

There are many projects in the planning stages, however there are no hydropower systems in operation at the moment. Examples are HPP Karura and the 700 MW High Land Falls system, both of which are situated on the Tana River. Furthermore, by modernizing and expanding the current facilities, an additional 120 MW of capacity might be added.

Table 5: Installed Small, Mini & Pico Hydropower plants in Kenya

Small Hydropower[42]	**Installed Capacity (MW)**	**Year [44]**
Nzoia II	20	Not Completed
Gitungi	7.51	Not Completed
Virunga	7.56	Not Completed
Total not completed	***35.07***	
Gura Power station	5.8	2022
Mutunguru	7.8	2019
Imenti	0.9	2009
Kathamba	0.001	2001
Thima	0.01	2001
Tungu - Karibu	0.01	2000
Mujwa	0.01	NA
Ten wek	0.32	NA
Diguna	0.4	1997
Savani	0.09	1927
Brook bond 4	0.24	NA
Brook bond 3	0.18	NA
Brook bond 2	0.1	NA
Brook bond 1	0.09	NA
James finaleys 5	1.1	1999
James finaleys 4	0.3	1984
James finaleys 3	0.1	1980
James finaleys 2	0.4	1934
James finaleys 1	0.3	1934
Sosiani	0.4	1955
Wanji 3 & 4	2	1952
Wanji 1 & 2	5.4	1952
Tana 5	4	1955
Tana 4	4	1954
Tana 3	2.4	1952
Tana 1 & 2	4	1932
Gogo falls	2	1958
Sagana falls	1.5	1955
Selgy falls	0.4	1952
Mesco	7.4	1933
Ndula	2	1925
Total completed	***53.651***	

High installation costs averaging US$ 2,500 per kW, inadequate hydrological data, effects of climate change, and a limited local capacity to manufacture small hydro power components have combined to impede exploitation of small-scale hydro-electricity. To mitigate these challenges, the Government is carrying out phased feasibility studies to establish the capacities of potential hydro power sites across the country.

2.4 *Bio-energy*

2.4.1 Biogas

Though the potential for biogas is far higher [2], the uptake still represents a small fraction of about 11.4 to 14.6% of the energy mix at household level in peri urban [29]. Additionally, it is estimated that Kenya has the capability to leverage biogas mechanisms to generate 624 GWh of electricity from agro-industrial waste and wastewater [40, 41]. Moreover, the nation possesses the capacity to generate biogas from sources such as dung, sisal, municipal waste, coffee, and other agricultural residues [13, 14, 42]. It has also been found that alternative substrates like water hyacinth, food waste, slaughter waste, and molasses distillery waste serve as effective biogas sources [43, 44]. It's crucial to recognize that diverse waste materials can act as substrates for the anaerobic digestion process [45].

Presently, the country is estimated to have 20,000 biogas systems, indicating significant progress. Supported by the Dutch government, the Kenya Biogas Program has overseen the installation of approximately 17,000 digesters across 36 counties. Noteworthy achievements include the successful establishment of commercial biogas plants for electricity generation by various institutions in Kenya estimated at 15.155 MW as outlined in **Table 6**.

Table 6: Kenya's smaller commercial biogas plants installed

NO	Company	Location	Bio waste	Size (m^3)	Capacity (MW)	Reference
1	Gorge Farm – Biojoule	Naivasha	Flower waste	5000	2.2	[30, 31]
2	James Finlay Ltd	Kericho	Flower and tea wastes	1,700	0.16	[32]
3	**Keekonyokie**	Kajiado	Slaughter waste	248	0.06	[33]
4	Pine power	Kilifi	Sisal waste and cow dung	750	0.15	[25, 34]
5	Isinya - Dave Flower Farms Ltd	Kajiado	Flower waste	400	0.1	[35]
6	Afrisol	Chaka, Nyeri	Slaughter waste	372	0.06	[25]
7	Sagana Oilvado Company	Murang'a	Avocado waste	1,400	0.34	[36]
8	Ereka Holdings Ltd	Simbi Roses	Flower waste	200	0.055	[25]
9	Dagoretti Slaughterhouse	Nairobi	Slaughterhouse waste	60	0.03	[37, 38]
10	Baringo Thermal Power Station	Baringo	Prosopis Juliflora	-	12	[45]
Total					***15.155***	

The Baringo biogas Power plant, powered by plant material from the Mathenge tree, boasts an installed capacity of 12MW, contributing 8.4MW to the grid, leveraging the abundant growth of

Prosopis juliflora in Baringo County. Also, biogas plants have been installed in a number of schools, including Siana Boarding Primary School (120 m^3), Kaimosi Teachers' College (200 m^3), Jomo Kenyatta University of Science and Technology (with a 385 m^3 biogas plant), and College of Agriculture and Veterinary Sciences (120 m^3). Large digesters have been built by these educational institutions with the combined goals of saving money by lowering dependency on the procurement of conventional fuel and providing training in biogas technology. This proactive approach shows their commitment to sustainability, as they promote the use of environmentally friendly energy sources and provide students and the general public with useful information about biogas technology [2, 39]. Evaluating the efficiency and effects of biogas plants deployed in educational institutions could be a study area. The study would assess the financial, environmental, and educational advantages of these installations, as well as the decrease of greenhouse gas emissions, cost savings from less fuel purchases, and the success of the community's and students' access to biogas technology training. Furthermore, investigating the difficulties and ideal procedures for setting up and managing biogas plants in educational environments would yield insightful information for subsequent projects.

2.4.2 Biomass

Biomass encompasses energy derived from various solid, liquid, and gaseous sources, including fuel wood, charcoal, ethanol, bio-diesel, and biogas. In Kenya, biomass accounts for 70% of the final energy demand, satisfying over 90% of rural household energy needs, mainly sourced from charcoal, wood-fuel, and agricultural waste. In addition, the collective sources have an installed electric capacity potential ranging from 29 to 139 MW, constituting approximately 3.2% to 16.4% of the total electricity generated. The government acknowledges substantial potential for power generation using forestry and agro-industry residues, notably bagasse, with a total cogeneration potential of 193MW, although the utilization remains untapped [17]. The Mumias Sugar Company, functioning as an Independent Power Producer [46], has faced closure due to challenges such as outdated technology, financial mismanagement, and fluctuating world sugar prices, despite its 35MW energy production capacity [47]. The closure has led to job losses, economic instability, and disruptions in fuel and sugar supply, underscoring the need for collaborative efforts among government, stakeholders, and the business sector to devise sustainable solutions.

Under the Feed-in Tariff [48] policy, biomass energy resources for electricity generation can fetch a fixed tariff not exceeding US Cents 10 per Kilowatt-hour, facilitating the approval of an 18MW cogeneration project using cane bagasse in Kenya's coastal region. Opportunities for biofuel production and processing, particularly from Jatropha and sweet sorghum, exist in various regions, including Galana and provinces like Eastern, North-Eastern, Rift-Valley, and Nyanza. Moreover, consultancy prospects are available for research and capacity building in bio-technology and related industrial potentials. Exploiting opportunities within other sugar factories, estimated at up to 300MW, remains an untapped potential awaiting exploration and utilization.

2.5 *Tidal energy and Wave power*

The tidal Stream Energy resources in Kenya are abundant for electricity extraction with proper site planning and optimization of the ocean energy converters. Characterization, mapping and tapping of the tidal resource reduce uncertainties thus increase and advance investment value of the current green energy initiative. In accordance to the theoretical calculations and simulations, an estimate of 1.9 GW (16.5 TW/h per annum) of tides and tidal power can be extracted averaged across the fortnightly tidal cycle whose resource potential can be higher with deployment. Currently there are no installed tidal or wave energy technology systems in Kenya. The possibility for using Mombasa and Lamu's tidal energy resources is highlighted by a study done [49]. However, it highlights a number of obstacles, including high capital expenditures, unstable political environments, fluctuations in the yearly energy density, technological advancements, and human limitations. Since the present expenses are higher than those of the energy systems that are currently in place, taking strategic action is necessary to address these issues. This could mean creating networks and regulations with the goal of maximizing the potential of ocean energy and promoting its development. To get over these challenges and maximize the exploitation of tidal energy in the area, more research should concentrate on investigating novel finance strategies, improving technological prowess, and bolstering human capital.

Wave power is the capture of energy of wind waves to do useful work for example, electricity generation, water desalination, or pumping water. A machine that exploits wave power is a wave energy converter (WEC). There are no installed wave energy systems although Blackbird International Corporation (BBRD) is planning to build a wave farm in Kenya. The project involves the construction of a 100MW wave energy farm and will be developed in phases. It includes the construction of power related infrastructure, the installation of turbines and power control units, and the laying of transmission lines.

Research conducted by Uppsala University (UU-WEC) in Kilifi, Kenya, demonstrated the potential of WEC as a solution for off-grid water desalination systems along the coastal regions [50]. The study revealed that the average tidal energy in the area is around 6.5 kW/m, with the peak values occurring in August at 10.5 kW/m and September at 10.2 kW/m. The findings suggest that a coastal community comprising approximately five thousand residents can be supplied with freshwater by employing just ten WECs, each with an installed capacity of 20 kW. There is need to establish a comprehensive framework to address barriers to exploiting tidal and wave energy in Kenya. Policymakers should prioritize creating supportive networks and regulations despite challenges like high capital expenditures and political instability. Further research should focus on novel finance strategies, technological enhancements, and human capital development to fully exploit ocean energy potential.

2.6 Hybrid Renewable Energy

Kenya is developing hybrid renewable energy facilities. Meru County's "Meru County Energy Park" is the only hybrid project in the country. The combination of wind, solar PV, and battery storage is used in this substantial installation. The facility will likely generate 80MW of power when it is finished. Up to 20 wind turbines and more than 40,000 solar panels are anticipated to be present at the project. Its renewable energy is planned to power more than 200,000 homes[51, 52]. In addition, a notable development in the area's energy environment is the Gitwamba Hydro Hybrid Power Plant, which is located in Kirinyaga. Designed to accommodate the varying river flow rates throughout the year, this cutting-edge plant combines solar and hydro power technology. When it rains, the hydro plant provides extra capacity, and during the dry season, the solar system augments power generation. Day or night, Kirinyaga County consumers are guaranteed a steady base load supply thanks to this dual strategy. The Gitwamba hydropower plant has a total capacity of 170 kW and is composed of a hydro component that can generate 50 kW when designed for a design flow of 0.65 m^3/s [53]. This dynamic configuration highlights the region's dedication to sustainable and dependable electricity generation while also enhancing energy resiliency.

Kenya has demonstrated its commitment to sustainable electricity generation through the establishment of hybrid renewable energy facilities like the Gitwamba Hydro Hybrid Power Plant in Kirinyaga and the Meru County Energy Park. While the Gitwamba plant mixes solar and water electricity to maintain a consistent base load supply, the Meru County Energy Park incorporates wind, solar PV, and battery storage with the potential to power over 200,000 homes. Inspiring further investment and cooperation for a cleaner future, these projects demonstrate Kenya's commitment to renewable energy and energy resilience.

2.7 Green Hydrogen

East Africa countries like Kenya has made great steps in the development of renewable energy, but there is still much unrealized potential for producing green hydrogen, a sustainable and clean fuel. Comprehensive research on Kenya's potential for producing green hydrogen is still lacking, which is necessary for well-informed decision-making and strategic planning [46]. It is imperative to investigate the viability and potential of producing green hydrogen in order to diversify Kenya's energy sources, improve energy security, and support worldwide decarbonization initiatives. The successful implementation of Kenya's Green Hydrogen Plan and Execution Strategy requires a clear, focused, and supportive atmosphere built on strong, well-aligned pillars to establish a prosperous green hydrogen industry as shown in **Figure 2.**

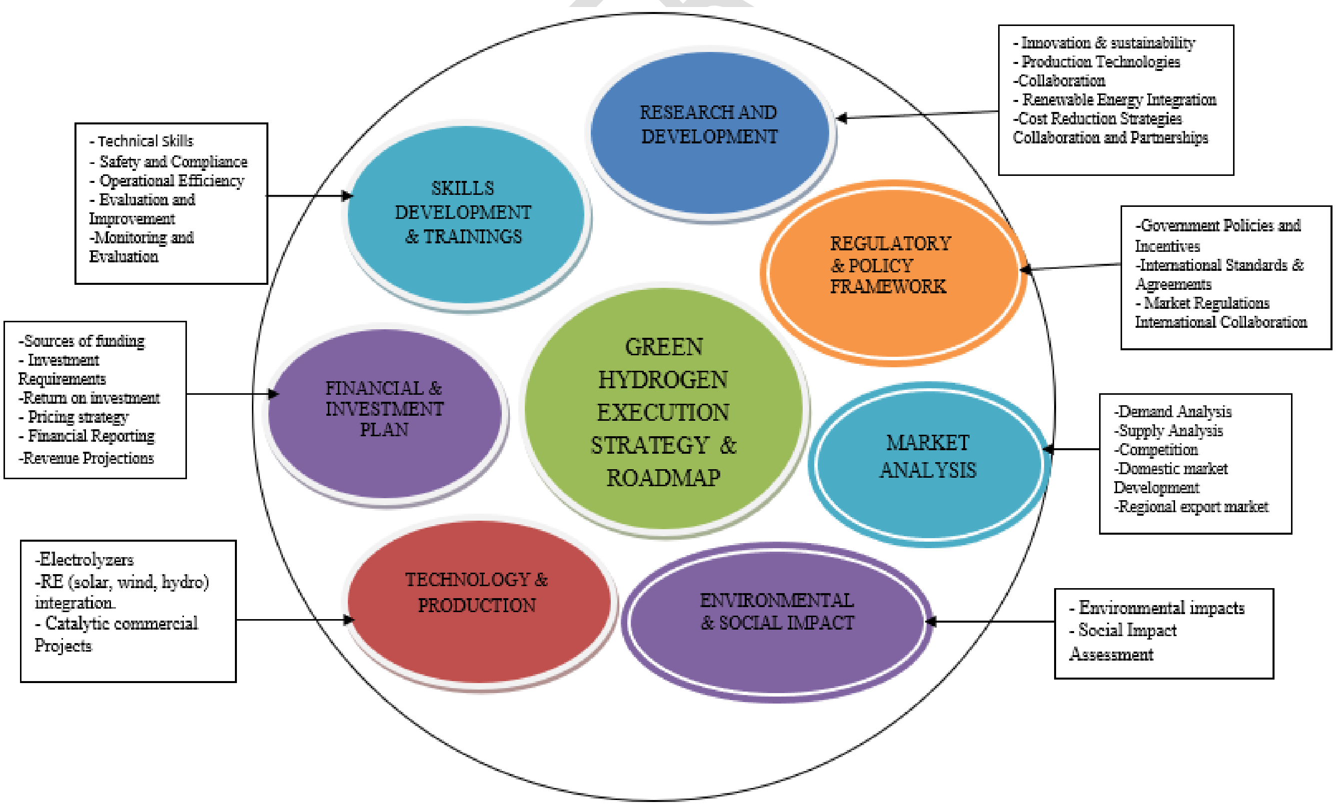

Figure 2: Kenya's Green Hydrogen Plan and Execution Strategy

Green hydrogen refers to hydrogen gas that is produced using renewable energy sources, such as solar or wind. Usually, electrolysis is used in the process, which uses an electric current to split water into hydrogen and oxygen. The hydrogen formed in this method is referred to as "green hydrogen" because the power employed in it initiates from renewable sources. This is for the reason that the procedure produces no carbon emissions, which makes it a more environmentally friendly choice than traditional hydrogen making processes that depend on fossil fuels. The significance of green hydrogen lies in its potential to serve as a clean energy carrier and storage solution. It can be used in many applications, including powering fuel cells in vehicles, providing heat and power in industrial processes, and even generating electricity. As the world seeks to transition to a low-carbon economy, green hydrogen offers a promising roadmap to decarbonize sectors that are hard to electrify directly, such as heavy industry and long-haul transportation.

Kenya intends to implement green hydrogen as a renewable energy source; Phase I (2023–2027) would concentrate on the installation energy of 150MW and 100MW of electrolyzers. By taking this action, it is anticipated that the amount of nitrogen fertilizer imported will be reduced by roughly 20%, or 100,000 tonnes annually. Phase II (2028–2032) aims to increase capacity with 350–450 MW of installed capacity and 150–250 MW of electrolyzers, with the goal of substituting 50% of nitrogen fertilizer imports, or 300,000–400,000 tonnes per year. The Kenyan government intends to continue these initiatives and look into export-oriented opportunities after 2032.

Green hydrogen, produced from renewable energy sources such as the abundant solar, offers significant potential for Kenya's economy, particularly in the sectors of industry, transport, and power. Firstly, green hydrogen can significantly improve Kenya's balance of payments. By producing green hydrogen domestically, Kenya can reduce its reliance on imports of hydrogen-based commodities such as nitrogen fertilizer and methanol. This shift not only lessens the nation's dependence on foreign imports but also opens up opportunities for export, leveraging Kenya’s strategic position as a regional trading hub. As a result, the production and export of green hydrogen derivatives can positively impact Kenya's balance of payments, enhancing economic stability and growth.

In addition to economic benefits, green hydrogen has the potential to enhance food security and agricultural resilience in Kenya. The local production of nitrogen fertilizers, facilitated by green hydrogen will ensure better availability and accessibility for Kenyan farmers. This will improve fertilizer supply which is crucial for boosting agricultural productivity, resulting to increased crop yields and overall food production. Furthermore, the use of locally produced green fertilizers will supports sustainable farming practices, adding value to agricultural produce and mitigating the impact of international market fluctuations. This self-sufficiency in fertilizer production strengthens the agricultural sector's resilience and contributes to food security in the country.

Green hydrogen moreover plays a critical role in driving green industrialization and decarbonization efforts. By establishing manufacturing value chains devoted to making green hydrogen and its byproducts, the nation can stimulate the growth of numerous industries. This industrialization will create employment opportunities across the whole green hydrogen value chain and supports the growth of the renewable energy sector. Additionally, green hydrogen industry can serve as a stable anchor off-taker, driving power grid extension and enhancing electricity access for Kenyan citizens. Substituting conventional hydrogen commodities derived from fossil fuels with sustainable alternatives not only supports global decarbonization efforts but also creates new export opportunities for low-carbon products. This will position East Africa countries such Kenya as a leader in the green economy and contributes to achieving the SDGs.

Lastly, the potential for green hydrogen to attract significant public and private investments cannot be overlooked. Investment in the green hydrogen value chain, encompassing power generation, hydrogen production, and downstream industrial facilities, will promote economic diversification, job creation, and industrial growth. By launching a robust green hydrogen infrastructure, countries can position itself as a key player in the global green economy, driving sustainable development and long-term economic prosperity. In general, green hydrogen holds significant promise for Kenya by reducing import dependency, enhancing food security, driving industrialization, and attracting investments. These benefits collectively contribute to sustainable economic growth, positioning Kenya as a leader in the transition to a low-carbon future.

2.8 Proportion of installed and under development renewable energy sources in Kenya

Table 6 outlines the national energy mix, development levels, potential capacities, current statuses, and the percentage of exploitation. Kenya's peak demand has risen gradually from 1,044 MW in 2008 to 2,149 MW in 2022, stressing the crucial need for development to keep up with demand. **Figure 3** presents Kenya’s peak demands for the period 2008-2022.

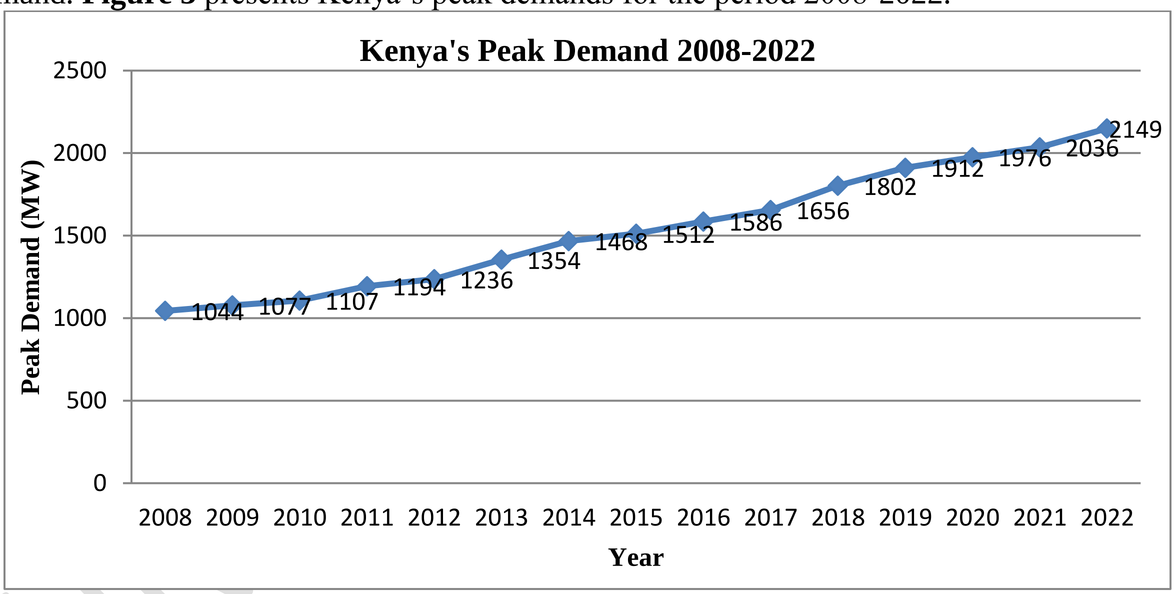

Figure 3: Kenya’s peak demands from 2008 to 2022

Kenya now generates 2453.9 MW of renewable energy, but ongoing projects will increase this to 3982.9 MW. The review results are in line with other researches [29]. Approximately 75.2% of the nation's total generation is derived from hydro, wind, solar, and bioenergy sources, which together account for 25.5%, 13.3%, 7.4%, and 0.1% of the installed capacity. Geothermal energy accounts for the remaining 28.8%. The current rates of exploitation for hydro, geothermal, wind, solar, and bioenergy are 10.7%, 9.4%, 7.3%, 1.6%, and 1.5%, respectively, demonstrating a notable underutilization of their potential. The figures provided suggest that the available resources, including hydro, geothermal, wind, solar, and bioenergy, are not being fully utilized, indicating a considerable underutilization of their potential capacity.

Table 7: Energy mix, degree of development, potential capacities and % exploited

Energy Source		***Current Status***			***Installed and Underdevelopment***		
	Potential (MW)	**Capacity (MW)**	**Percentage Contribution**	**Percentage Exploitation**	**Capacity (MW)**	**Percentage Contribution**	**Percentage exploitation**
Hydro	7812	833.8	25.5	*10.7*	1026.23	21.4	13.1
Solar	15,000	242.6	7.4	*1.6*	372.6	7.8	2.5
Wind	6,000	435.5	13.3	*7.3*	996.5	20.8	16.6
Geothermal	10,000	940	28.8	*9.4*	1496	31.2	15.0
Hybrid	-	0	0.0		80	1.7	
Bio Energy	131	2	0.1	*1.5*	11.6	0.2	8.9
Total RE		***2453.9***	**75.2**		**3982.9**	**83.1**	
Thermal	-	810.52	24.8		810.52	16.9	-
TOTAL		**3264.42**	100		**4793.45**	100.0	

2.8 Challenges and Future opportunities to Renewable Energy.

a) Energy Policy

The Kenyan government has recently advanced policy by enacting a number of initiatives designed to increase investment in renewable energy. The Energy Act No. 1 of 2019 is one of the major measures. It gives the Ministry of Energy and Petroleum the authority to create energy strategies, make land acquisition for energy projects easier, and promote an environment that is conducive to investment. These efforts are aided by the creation of the EPRA, which regulates renewable energy operations, gathers energy data, and establishes environmental compliance, licensing, and tariff guidelines. The Energy and Petroleum Tribunal has also been charged with settling conflicts in the industry and guaranteeing fair results.

Projects for off-grid living and rural electrification, like the Garissa Solar Power Plant, are being advanced by the Rural Electrification and Renewable Energy Corporation (RERC), which is essential to Kenya's renewable energy landscape. The Multipurpose Energy Project Development and Resource Allocation Committee provides guidance on these matters while the Renewable Energy Resource Advisory Committee advises. In addition, policies such as the Renewable Energy Feed-in Tariff System are implemented with the intention of cutting greenhouse gas emissions and diversifying the sources of electricity generated locally. A number of obstacles still need to be overcome in order for the industry to flourish and make the best use of its resources. These obstacles include difficult licensing processes, restricted local production capacity, and finance delays.

The significant potential for producing electricity in the Republic of Kenya from renewable sources has been acknowledged by the authorities of that nation. So, in its all-inclusive power development plan that runs from 2017 to 2037, it has placed a strong emphasis on increasing the production of RE. By 2037, it is hoped that the country's installed power capacity will be slightly over 60% supplied by renewable energy. Further, the change in Kenya's energy policy, shifting from FiT [54] to the RE Auction Policy (REAP), has raised concerns, according to the International Energy Agency (IEA) [55]. The Reap framework allows the Kenya Power and Lighting Company (KPLC) to consider only the cheapest bids from independent power producers (IPPs), potentially slowing down investments in renewable energy. The transition was prompted by a task force appointed in 2021 to address high electricity costs, leading to power purchase agreement [56] renegotiations. The IEA warns that this shift may hinder the country's efforts to close its energy access gap and achieve renewable energy targets, despite the potential for adding up to 2,000 megawatts of renewable energy capacity by 2028 if the auction scheme is effectively implemented.

b) Disputes and conflict

Conflicts and disputes are preventing Kenya from developing its renewable energy industry and creating serious obstacles to its expansion. The recent change in policy from FiT to the REAP is a key point of dispute. Conflicts over power purchase agreements (PPAs) and the selection criteria for projects under the new framework have arisen between the government and IPPs as a result of this move. A task team established in 2021 with the goal of addressing consumers' high electricity costs was the impetus for the move. On the other hand, uncertainties have been brought about by PPA renegotiation and the introduction of the auction system, which has resulted in legal challenges and project execution delays. The criteria for selecting the cheapest bids based on financial and technical evaluations have further fueled disagreements, creating an environment of uncertainty for investors.

Furthermore, local residents and environmental organizations are worried about the possible harm that renewable energy projects could do to livelihoods and ecosystems. Land use, water resource, and environmental conservation conflicts have resulted in project delays and occasionally project cancellations. In addition to impeding the attainment of renewable energy targets, these disagreements discourage prospective investors by fostering an unattractive investment climate due to regulatory and policy uncertainties.

KenGen serves as an exemplary model for resolving social, political, cultural, and economic conflicts through diverse strategies such as competition, avoidance, collaboration, compromise, accommodation, mediation, public participation, and inclusiveness [57]. Their comprehensive approach underscores the importance of employing various conflict resolution methods tailored to specific contexts and stakeholders involved. In order to promote sustainable development, these issues must be resolved via open and inclusive communication, involvement of stakeholders, and rigorous evaluation of the effects renewable energy projects will have on the environment and society.

c) Environmental issues

East African RE sources face environmental obstacles that compromise their efficacy and dependability. During droughts, hydroelectric power generation is particularly vulnerable to variations in water supply, which can result in energy shortages and a dependence on less sustainable options. Further impediments to the implementation of geothermal [58], solar and wind energy include groundwater contamination, greenhouse gas emissions, land subsidence, and disturbance of wildlife. However, negative consequences can be reduced with careful planning, environmental impact assessments, and mitigating measures, guaranteeing Kenya's sustainable adoption of solar, wind, and geothermal technology. The environmental effects of solar energy often entail landscape modifications, including vegetation removal, land leveling, soil compaction, removal of unnecessary roads, and the construction of main access roads [59]. Prioritizing techniques to lessen environmental effects and improve the nation's long-term reliance on renewable energy sources should be the focus of future study. Further research should prioritize strategies to mitigate environmental impacts and enhance the long-term viability of renewable energy sources in the country.

d) Energy Storage

Energy storage systems provide a flexible and adaptable way for National Grid Renewables' utility and commercial clients to access a multitude of benefits. When combined with renewable energy sources, storage's quick response and ramping capabilities work wonders to balance supply and demand [60]. There are obstacles in the way of integrating these various storage options into the national grid, though. The national grid faces challenges in maximizing storage capacities, guaranteeing interoperability with diverse power generation technologies, and managing the intermittent nature of renewable energy sources [61]. Improving the dependability and effectiveness of energy storage in Kenya's national system requires addressing these issues.

The challenges preventing the smooth integration of various energy storage solutions into Kenya's national grid should be the main focus of future study. Research should focus on optimizing storage capacity, making sure that different power generation technologies work together, and creating plans to deal with the intermittent nature of renewable energy sources. In order to improve the reliability and effectiveness of energy storage systems in Kenya's national grid and create a more durable and sustainable energy infrastructure, this research will provide crucial insights.

e) Renewable Energy Integration to Power System

There has been a notable upswing in attention directed toward incorporating renewable energy sources into power systems [62, 63]. This heightened focus arises in response to the escalating demand for sustainable and clean energy solutions. While this transition holds paramount significance, it brings forth a set of challenges that necessitate careful consideration to ensure the reliable and effective functioning of power systems [13]. The primary challenges revolve around integrating renewable energy sources into the grid and encompass diverse aspects such as managing intermittency, improving grid stability, optimizing energy storage, and refining policy frameworks. By acquiring a comprehensive understanding and adeptly addressing these challenges, power systems can seamlessly assimilate renewable energy sources. This, in turn, assumes a pivotal role in advancing towards a more sustainable future.

f) Future opportunities

As a result of population growth and rising energy consumption, especially for renewable energy, Kenya's Vision 2030 plan and the Least Cost Power Development Plan (2011–2031) predict that 15,065 MW of power will be needed by 2030 [64, 65]. Regular surveys and resource assessments of renewable energy resources are required under the Energy Act, which also provides RE energy projects that the government has started up have opened doors for Independent Power Producers (IPPs) and private investors to participate in the building, installation, and financing of these projects [66]. There are additional manufacturing opportunities for solar and wind energy-related parts and accessories. Furthermore, there may be opportunities for growth and investment in Kenya's renewable energy sector due to undeveloped resources such green hydrogen, concentrated solar power energy storage, biomass gasification, on-shore ocean energy, and bio-refinery technology.

3. Conclusion

The review established that Kenya's energy mix predominantly consists of green energy with geothermal, hydro, wind, solar and bio-energy accounting for roughly 75.2% generation in the year 2023. The results contradict the EPRA reports [67]. The remainder is filled by thermal and imports. Thermal is assumed to be constant for this case. As more investments are directed towards reducing dependence on expensive hydro plants and lessening reliance on hydroelectricity, geothermal energy and green hydrogen are expected to experience continuous growth. This trend is particularly significant given the challenges hydroelectricity faces during periods of drought.

The utilization rates for Kenya as an example in East Africa for hydro, geothermal, wind, solar, and bioenergy are at 10.7%, 9.4%, 7.3%, 1.6%, and 1.5% respectively, indicating significant underutilization of their potential capacity among East African countries. By 2032, the Kenyan government aims to install 350–450 MW of power generation and 150–250 MW of electrolyzer capacity to substitute 50% (300,000–400,000 tonnes per year) of nitrogen fertilizer imports.

Thus, to bridge the gap between existing capacity and actual utilization/potential, rigorous efforts are needed, paving the way for a more resilient and environmentally sustainable energy landscape in Kenya and beyond. Enhanced information availability can drive East Africa's broader adoption of renewable energy sources by influencing both public policy and private decision-making. However, the complex relationships between renewable energy and sustainable development remain poorly understood. To close this knowledge gap, it is crucial to support comprehensive policies, encourage cross-sectoral dialogue, and enhance transparency. Additionally, increased research efforts can dispel uncertainties about specific renewable energy sources, ensuring a more informed and confident transition.

4. Recommendations

To fully harness East Africa's plentiful renewable energy potential and address the underutilization of hydro, geothermal, wind, solar, and bioenergy resources, it is imperative to prioritize enhanced information disclosure, comprehensive policy frameworks review and encourage private public investors partnership. By setting commitments to initiatives such as Kenya's Vision 2030 and the Climate Change Act of 2016, countries can stimulate public awareness, education, and institutional capacity-building in renewable energy. Increased research efforts are crucial to dispel doubts and ensure a smooth transition towards sustainable energy. East Africa can lead the way in creating a resilient and environmentally sustainable energy landscape by bridging the gap between current capacity and actual use, thereby making a significant contribution to global efforts to mitigate climate change and accomplish SDGs.

For green hydrogen, Kenya and other East African countries are well-positioned to harness solar energy for green hydrogen production due to their satisfactory solar irradiance and expanding renewable energy infrastructure [68, 69]. A comprehensive evaluation of the techno-economic viability of solar green hydrogen production in Kenya is important, highlighting the cost benefits of commercializing byproduct oxygen. This should include a thorough technical feasibility study focusing on solar resource assessment using satellite data and field measurements to determine the solar potential across all regions of Kenya. Additionally, a comparative analysis of several solar-powered electrolysis technologies is essential to identify the most suitable option based on cost, efficiency, and scalability. Furthermore, the study should develop a conceptual design for the hydrogen production system, incorporating solar panels, electrolyzers, storage, and distribution infrastructure.

Enhancing the dependability of RE sources through energy storage, like pumped hydro storage, is necessary [36, 70]. This will improve the dispatchability of power output, which may facilitate the power system operator's scheduling of generators. Additionally, it is essential to assess the effectiveness of East Africa's RE policy, highlighting implementation challenges and their influence on the private sector. Furthermore, exploring approaches for community involvement and the effect of foreign direct investment on local economies is crucial. Lastly, exploring global collaboration and mechanisms for knowledge transfer is imperative.

Declaration of generative AI in scientific writing

During the preparation of this work the authors used ChatGPT to improve readability and language of the text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication

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