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Review Article

A Review of Energy Development and Utilisation in Kenya

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Abstract - *Energy is essential for development and comprises a significant portion of a country's budget. The achievement of Vision 2030 development goals and the Big Four Agenda for Kenya depends, among other factors, on the ability to generate, supply and consume clean, affordable, sustainable and reliable energy. Kenya's energy sector is characterized by a diversified energy mix consisting of biomass (68%), petroleum (22%), electricity 9 % and others (1%). This report reviews energy sources comprising humans and animals, fuel wood, hydropower petroleum, solar, wind, coal, nuclear and biomass in Kenya. It presents the current status of development and utilisation of the various energy sources, challenges hindering their utilisation, and possible mitigations and future trends of these energy resources in Kenya. Presently, energy consumption in Kenya relies on natural resources and largely on petroleum fuel, with a large share of challenges. Government plans and strategies for future energy supply are focused on the development of renewable sources, both for energy security and the attainment of sustainable development goals. Further research and development on renewable energy sources, hybrid technologies, energy-efficient systems, and energy management strategies is important to unlock the energy generation potential and meet the increasing energy demand.*

Keywords - *Energy efficient systems, Energy management, Hybrid technologies, Kenya, Renewable energy sources.*

1. Introduction

Energy is a key player in generating wealth and a significant component in economic development globally. In developing countries, energy demand has become an essential factor due to industrial development and rapid increase in population. In Kenya, energy is a fundamental factor towards the realization of sustainable development. The achievement of the economic pillar of Kenya Vision 2030 and the Big Four Agenda depends, among other factors, on the ability to generate, supply and consume clean, affordable, sustainable and reliable energy [1]. The Kenya Vision 2030 is a development blueprint anchored on 3 pillars, namely, Economic, Social and Political. The goal of the vision is to create a globally competitive and prosperous country with a high quality of life by the year 2030. It aims to transform Kenya into a newly industrialising, middle-income country that provides a high quality of life to all its citizens in a clean and secure environment. The Economic Pillar aims to achieve and sustain an average steady economic growth rate of 10% annually until 2030. The Social Pillar seeks to build a just, cohesive society with social equity in a clean and secure environment. The political pillar envisions an issue-based, people-centered, result-oriented and accountable democratic system. The Big Four agenda, on the other hand, is a development plan with four priority areas, namely, food security, affordable health care, affordable housing and robust manufacturing sector (19). Sustainable energy is one of the infrastructural enablers of the three "pillars" of Vision 2030 and priority areas of the Big Four agenda. The level and intensity of commercial energy use in a country is a key indicator of the degree of economic growth and development. Kenya is, therefore, expected to use more energy in the commercial sector on the road to 2030. The government of Kenya targets new sources of energy through the exploitation of geothermal power, coal, and renewable energy sources and connecting to energy-surplus countries in the region in order to bridge the energy gap (19). This study builds knowledge on gaps and opportunities existing in the energy sector for the development of sustainable energy systems. The detailed analysis of each energy source in the energy mix has not been presented in any other review.

2. Background Information

According to the Kenya National Bureau of Statistics (KNBS) census report 2019, Kenya is a developing country with a population of 47.6 million and a growth rate of 2.2 %

[2]. This figure is projected to reach 91.6 million people by the year 2050. Consequently, energy demand is growing just as the population increases, as well as growth in the economy. The energy sector in Kenya is characterized by a highly diversified energy mix largely dominated by petroleum and electricity. Wood fuel provides the basic energy needs of rural communities, urban poor, and the informal sector. An analysis of the national energy consumption patterns shows heavy dependency on wood fuel and other biomass, accounting for 68% of the total energy consumption. Petroleum accounts for 22%, electricity 9%, and other energy sources at 1%. The countries' energy generation capacity was reported at 2,812 MW in 2019 and is projected to increase to approximately 5,000 MW over the next 5 years and to 26,000 MW by 2030 [3]. According to SusWATCH, the energy production mix will include 52.1% of hydro, 32.5% of fossil fuels, 13.2% of geothermal energy, 1. 8% of biogas cogeneration, and 0.4% of wind [4].

The high dominance of fossil fuels in Kenya's energy mix has presented numerous challenges, including price volatility, supply uncertainty, foreign currency requirements and environmental pollution. To overcome these challenges and achieve the climate target and Sustainable Development Goals (SDGs), the government has increased its efforts towards promoting renewable energy programmes. The former President of the Republic of Kenya reiterated this commitment during the UNFCC-COP 26 held in Glasgow in November 2021. In recognition of its efforts, the country was ranked fifth globally in an annual Bloomberg index measuring investments and opportunities in clean energy. Moreover, this underlines the country's position as the centre of renewable energy in Africa, owing to the higher contribution of solar, wind, and geothermal capacity to the energy mix. The three energy sources account for up to 65 % of the country's energy sources [5].

The Ministry of Energy and Petroleum (MoEP) is the lead government ministry in charge of the energy sector development, while the Energy and Petroleum Regulatory Authority (EPRA) is the sector regulator. The powers of the ministry are vested in the Constitution of Kenya 2010. The constitution gives the government power to regulate and administer natural resources on behalf of the public. The MoEP is responsible for establishing the energy policies under the Fourth Schedule of the constitution [6]. The Energy Act 2019 and its subsidiary legislation are the main act regulating the energy sector.

The law regulates the establishment of energy sector entities, the promotion of renewable energy, the production, supply and use of geothermal energy, midstream and downstream petroleum and coal activities, and other energy sources. Further, the act established the Energy and Petroleum Regulatory Authority ("EPRA") in place of the Energy Regulatory Commission ("ERC"). The authority is mandated to regulate the energy sector fairly, transparently and predictably, consistent with government policy and development Agenda, while being sensitive to stakeholder interests [7]. The Feed in Tariff Policy 2012 was adopted in Kenya to meet its targets for tackling climate change by reducing reliance on fossil fuels. Increasing energy generation to 5,221 MW by 2022 was one of the priorities under the country's Third Medium Term Plan. The aim was to promote the development and use of renewable energy sources, intending to create a reliable, adequate, cost-effective energy supply regime to support industrial development. This was to be achieved from the energy sources shown in Table 1.

Table 1. Projected power generation capacity per source [1, p. 36]

S/No.	Power Projects/Source	Projected Capacity (Year 2022)	% Capacity
1	Hydropower	93MW	1.78
2	Geothermal	913MW	17.49
3	Wind	800MW	15.32
4	Biomass	157MW	3.01
5	Solar	442MW	8.47
6	Coal	328MW	6.28
7	Imports	400MW	7.66

It is interesting to note that, in the future, geothermal energy will dominate the energy landscape at 17.49%, followed closely by wind at 15.3%. This increase is attributed to the interventions by the Government of Kenya to encourage independent investment in the wind sector and the introduction of a feed-in tariff (FiT) [8]. Future reduction of hydropower energy is associated with unreliable supply, occasioned by the effects of climate change. The trajectory towards low energy imports is a good indicator of energy security and price stability in the future. The installed energy capacity comprises both grid-connected units and off-grid units. Table 2 compares the installed capacity in the financial year 2020/2021 and 2021/2022.

Table 2. A comparison of the installed capacity for Kenya's power plants in the financial 2020/2021 and 2021/2022 [32]

Source	2020-2021		2021-2022	
Hydro	838	28.20%	837.58	27.24%
Geothermal	863.13	29.04%	949.13	30.87%
Wind	435.5	14.65%	435.5	14.17%
Thermal	720.32	24.24%	6246.32	21.02%
Solar	90.25	3.04%	170	5.53%
Biomass	2	0.07%	2	0.07%
Off-grid	22.8	0.77%	33.81	1.10%
Total	**2,972**	**100.0%**	**3,074.34**	**100.0%**

The installed capacity increased from 2,972 MW as of June 2021 to 3,074.34 MW as of June 2022. Geothermal and solar generation increased by 86 MW and 120 MW, respectively. EPRA observed that the increased contribution from geothermal and solar was attributed to the addition of 40 MW from Cedate Solar power plant, 40 MW from Selenkei Solar power plant, 40MW from Malindi Solar and 86 MW from Olkaria 1 unit 6 to the grid, with an installed capacity of 949.13 MW, geothermal accounts for 30.87% of the total installed capacity up from 863.13 MW in June 2021. The installed solar power capacity increased to 5.53%, up from 3.04%. Thermal power electricity capacity was reduced from 748.7 MW in June 2021 to 646.32 MW in June 2022 following the retirement of the Tsavo Power plant. (32).

A comparison of the energy contribution by source was carried out for the period between 2020/2021 and 2021/2022. Table 3 presents a comparison by energy source between the two reporting periods.

Table 3. A comparison of contribution to energy generation by source [32]

Energy source	2020/2021		2021/2022	
Hydro	4,142.18	34.23%	3,348.71	26.47%
Thermal	940.03	7.77%	1,647.75	13.02%
Wind	1,700.45	14.05%	2,052.26	16.22%
Geothermal	5,033.69	41.60%	4,953.15	39.15%
Bagasse/Biogas	0.33	0.00%	0.38	0.00%
Imports	196.55	1.62%	337.5	2.67%
Solar	87.94	0.73%	312.99	2.47%
Total	**12101.17**		**12652.74**	**100%**

The electrical energy generated increased by 4.55% from 12,101.17 GWh in June 2021 to 12,652.74 GWh in June 2022. Hydro and geothermal were the major energy sources, with a combined contribution of 65.62%, while wind and solar accounted for 18.69%. In the same period, the contribution from wind and solar increased by 352 GWh and 225 GWh, respectively. A detailed analysis of each of the energy sources/systems provides important information for decision-making regarding future perspectives on energy supply and national development.

This review synthesises published literature and reports on the level of development and utilization of various energy systems with particular emphasis on (i) the current status, (ii) the challenges and mitigation, and (iii) the future trends.

3. Materials and Methods

The review involved collating literature from journal articles, books, research and conference papers, discussion papers, book chapters, industrial and government reports and development plans. The reference materials were purposively selected based on their relevance to the study. The comprehensive literature review was conducted using electronic databases, including Science Direct and Google Scholar. The information gathered from the literature was analysed and discussed under the various sections of the review. Conclusions were drawn based on the results of the reviewed literature, while future perspectives were informed by the gaps and trends highlighted in the literature.

4. Review of Different Energy Systems

4.1. Human and Animal Energy

4.1.1. Current Status of Utilisation

Globally, there is widespread dependence on traditional forms of energy. In low-income countries, 80% or more of energy consumption comes from traditional sources. Humans and animals, as renewable traditional energy sources, are not considered despite contributing a significant proportion of the energy used in the rural areas of developing countries. Their omission is also reflected in policy recommendations and the academic texts on renewable energy sources and technologies, hence the phrase ‘forgotten renewables’’ [9]. Human and animal energy use to do work relies on the human and animal muscles. Either alone or organized into groups, humans and animals can do remarkable amounts of work in farming, construction, fabrication, and manufacturing.

For almost all of human history, transportation has largely depended either on the use of humans or on certain animals such as horses, camels, oxen, and occasionally more exotic animals such as elephants [10] The 2019 census data by the Kenya National Bureau of Statistics (KNBS) revealed that the 32.73 million (68.9%) Kenyans living in rural areas are characterised by the use of biomass, combined with human and animal power as main sources of energy; heavy dependence on agriculture and any small/medium-sized industries are usually those that process agricultural products; low-income population compared to their urban counterparts; working life dominated by hard physical labour and human drudgery is common and finally, unemployment and under-employment [2, 10]. Consequently, human and animal energy continues to power operations and equipment, especially in the agricultural production, construction and cottage industries. Some regions in the country, such as the Northern part, largely depend on animal energy, such as camels, for transportation. Donkeys are widely used in parts of central Kenya and Rift Valley, while oxen are commonly used in the Eastern part for farming. Inspite the wide use and importance of this form of energy, country data on utilisation is scarcely documented.

4.1.2. Challenges and Possible Mitigations

The main limitation of this form of energy is that the power output must be applied within a very short distance of its source. A society of this kind is sometimes referred to as a “low-energy society.” Low-energy societies, though stable, tend to be resistant to change [10]. Low efficiency is recorded in this form of energy due to limitations on capacity, skills and drudgery where timeliness is paramount. Since human and animal energy derives from foods, changes in diet can have a potentially significant impact on society. Cases of malnutrition may affect work output and efficiency. It is unsuitable where high precision and repeatability are desired.

The low efficiency makes this form of energy one of the costliest compared to others, and it is also affected by weather conditions and seasons, age and gender [9]. The high cost of modern and efficient technologies is a significant barrier to the adoption of this source of energy. Most rural poor lack the financial capacity to access these technologies that would make their work more efficient. Thus, increasing investment in technologies to harness human and animal energy should be emphasized as a form of renewable energy. Therefore, there is a need to increase the supply of secure, reliable and affordable energy to improve the quality of life among the traditional energy-reliant groups. Initiating programmes that will improve the livelihoods of the rural communities and thereby increase their purchasing power will enable them to afford simple technologies such as animal and handcarts, wheelbarrows and bicycles [9].

Environmental pollution is a possible occurrence in this form of energy. Animals such as donkeys can be excessively noisy, while bad odour from animal droppings and visual pollution are nuisances in some areas. Proper management of animals at household levels and regular cleanups is necessary to conserve the environment [10]. Fatal traffic accidents, especially along highways, have been a common occurrence, especially in areas with high animal populations. Vehicles collide with animals, and drivers swerve to avoid them, leading to accidents.

These distractions have led to the loss of lives, especially along the Nairobi-Nakuru highway. Addressing this challenge may involve having dedicated lanes on the roads for animals and humans to minimize obstruction. Containing these animals to prevent them from straying is important while imposing penalties against defaulters. Tagging of the animals will be necessary to trace them to the owners should any stray. Diverting food crops to provide “fuel” or animal fodder may result in food insecurity and malnutrition. Growing feeds for animals and increasing the manufacturing capacity for animal feeds will reduce competition with human food. Violation of human rights through child labour is one of the labour-related issues in this form of energy. These challenges are being addressed through the enforcement of labour laws and regulations. Subsequently, animal rights have emerged, and violators are liable for prosecution, resulting in lessening dependence on animal energy.

4.1.3. Future Trends

Human and animal energy will be with us for centuries. Although rapid technology development and adoption, leading to mechanization, are revolutionizing these human and animal energy-dependent sectors, eliminating them fully can only be an illusion. Improved economic growth and a rising standard of living are key contributing factors to reducing human and animal energy use. Human rights and labour legislation have played a big role in minimising dependence on human energy**.** The Kenya government, through the Ministry of Energy and Petroleum, has accelerated the connectivity of rural households to the national grid through various initiatives. The net effect is increased adoption and use of electricity-powered technologies and a significant phase down on human and animal energy in some areas. The fact that the use of human and animal energy is inevitable, at least in rural communities, calls for redesigning of equipment for this form of energy in order to acquire high efficiencies and increased output. Unfolding into the future is using novel technologies to harvest energy from the bodies of living subjects (humans and animals) for self-powered electronics [11]. This development is expected to advance, focusing on building self-powered electronics, especially for biomedical applications.

4.2. Firewood Energy

4.2.1. Current Status of Utilisation

Historically, the first fuel that humankind relied on in large amounts was wood due to its abundance in many places of the world and the fact that it can be gathered freely from the local environment. Wood is easy to handle and store, ignite, and burn in open fires and supplies most people’s energy needs for cooking, heating, and domestic comfort [10]. Wood fuel biomass is the most significant energy from primary source for consumption in Kenya, contributing to about 74% of the country's entire primary energy need. The consumption of wood fuel is expected to remain the country’s main source of energy for rural communities and urban poor in the foreseeable future [4].

According to Githiomi and Oduor, wood fuel meets over 93% of rural household energy needs, whilst charcoal is the dominant fuel in urban households [12]. Wood fuel is also used in cottage industries, which include the firing of lime and brick making, tobacco curing, fish smoking, jaggaries and bakeries, as well as small restaurants/hotels and, kiosks and learning institutions. Industries use wood for their thermal processes. Tea processing industries use firewood in boilers for curing in large amounts. Based on the national population for the year 2012, demand quantities for firewood and charcoal are estimated at 18,702,748 m^3 and 16,325,810 m^3, respectively [13]. Firewood is obtained in Kenya through locked woodlands, bushlands, forest fields, plantations, industrial residues and agriculture [4].

4.2.2. Challenges and Possible Mitigations

Small-scale burning of wood in domestic applications is inefficient. At best, only 10% of the heat liberated from the wood is used effectively in a traditional open fire [10]. Unsustainable supply, resulting from increased demand due to a rise in population growth, makes firewood unavailable. The issues of long-distance travel to collect firewood, accessibility, and government regulations on the use of forest resources have emerged. The government of Kenya imposed a ban on logging in public and community forests to control deforestation and other wrong forestry practices. Access to forest resources for firewood was restricted, resulting in supply constraints and the possibility of fines for violation [13]. Firewood scarcity is a gender issue due to the amount of time that has to be devoted to gathering it [10]. In Kenya, women and children can gather firewood for six hours daily. The net effect of this is that the bundles of wood to be carried back home may be too heavy to carry, upto about 50 kg. This limitation may result in serious health problems and violation of human rights. On the other hand, time is taken away from family activities, such as child rearing and other essential tasks. The loss of time severely impacts and restricts women's ability to improve their lot, such as by working outside the home or obtaining an education.

Further, wood smoke contains various large organic molecules known or suspected to cause cancer. Other smoke particles may increase susceptibility to respiratory illness and sore eyes. Atmospheric emissions from many small wood-burning stoves and fireplaces cause local air pollution, while excessive smoke production may cause fire hazards. High demand and excessive abstraction of wood have contributed to deforestation, degradation of land and water resources, destruction of ecosystems, loss of habitats, and ultimately global warming. Other barriers to the sustainable use of wood resources are the lack of quality standards and the high cost of improved stoves and their cleaner alternatives.

Similarly, local traditions and cultural norms prevent behavioural change. As mentioned in the energy bioenergy strategy 2020-2027, enhancing the enforcement of the range of policy and legal interventions that have been endorsed will lead to accelerated uptake of modern bioenergy [14]. The logging ban legislation has been implemented to regulate the use of forest resources. Agroforestry, a combination of food and wood production, offers a way to increase yields of food, firewood, and fodder for cattle.

Moreover, providing alternative renewable energy sources to substitute fuel wood and using improved technologies such as energy-saving stoves is the ultimate solution. Kenya has an ambitious target of achieving 100% access to modern cooking services by 2030, including efficient cook stoves for wood and charcoal, household biogas, and Liquidified Petroleum Gas (LPG) stoves, among others. Cleaner cooking is an important part of Kenya's climate plans. Increasing adoption of improved technologies, such as charcoal kilns with efficiency of over 25% to replace traditional charcoal earth kilns, would lead to a significant reduction of wood needed for firewood and charcoal [5].

4.2.3. Future Trends

Consumption of wood fuel in Kenya is expected to rise due to an increase in population growth. Further, forecasting future wood supply and demand revealed a gradual increase in supply and demand towards 2032. Supply is projected to increase from 31,372,531 m^3 to 35,727,900 m^3, with that of firewood increasing by 10.0% by the year 2032. Likewise, demand is estimated to increase to 50,712,100m^3, with that of firewood increasing by 16.1% by the year 2032. The projection of net balances shows an increasing deficit margin for wood into the future by 18.3%. In order to attain and maintain surpluses of firewood in future, Reducing Emissions from Deforestation and Forest Degradation (REDD+) intervention measures aimed at enhancing supply and curbing high and rising demand have been proposed. These interventions include promoting tree planting through capacity development and incentives, reducing wasteful processing and utilization, streamlining research recommendations, and effectively monitoring forestry development ([13]. However, it is doubtful whether the country could possibly grow enough wood to meet the increasing demand.

4.3. Hydropower Energy

4.3.1. Current Status of Utilisation

Hydropower is the world's largest producer of renewable energy and an important power supply option, contributing about 16% of global energy [15]. Hydropower offers clean, affordable, and reliable energy while meeting basic water, irrigation, and flood and drought control needs. It forms the single largest generation source for grid electricity in Kenya, providing about 677 MW of the total installed grid capacity. Large-scale hydropower production is estimated to reach 1500 MW, of which 1310 MW is feasible for projects with a capacity of 30 MW by 2030 [1]. The hydroelectric power generation potential areas are in five geographical regions, representing major drainage basins in Kenya, as shown in Table 4.

Table 4. Hydroelectric power generation potential areas [4]

Area	Amount
Lake Victoria	295 MW
Athi River	84 MW
Rift Valley	345 MW
Tana River	800 MW
Ewaso Ng'iro North River	146MW

Tana River region demonstrates the greatest potential for hydroelectric power generation. Small, mini and micro-hydroelectric systems (with capacities of less than 10 MW) are estimated to generate 3,000 MW nationwide. Installed grid connected small-scale hydroelectric projects contribute about 6.3 MW [4].

The total installed large hydropower capacity as of June 2022 was 838 MW. Kenya has an estimated small hydropower potential of 3,000 MW which remains unexploited. In the period under review, the energy generated from hydro decreased from 4,142.18 GWh to 3,349 GWh, as shown in Figure 1. The reduced hydro energy generated was attributed to poor hydrology, which contributed to low levels of Masinga, Kiambere, and Turkwel dams.

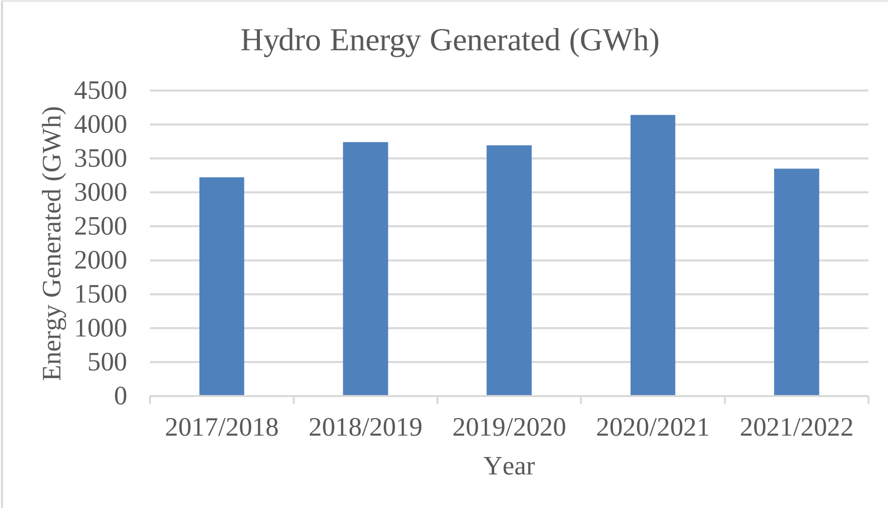

Fig. 1 Hydroenergy generated between 2017 and 2022 [32]

4.3.2. Challenges and Possible Mitigations

The challenges facing hydropower energy are: i) Vulnerability to the effects of climate change and the impact of natural conditions of hydrology and geology. These conditions are rarely constant or fully predictable, hence the uncertainties on the reliability of this form of energy. Hydrology determines plant power generation and revenues. Studies have observed that reliable data and climatic projections are prerequisites for sound hydropower project planning. Nevertheless, uncertainties may arise about future discharges because they could deviate from historical values due to the effect of climate change.

The problem is exacerbated by a lack of key instruments supporting increased resilience in the energy system, such as the availability of flood maps, the existence and enforcement of power plant silting, construction guidelines, and emergency plans to react to extreme weather events. This risk can be minimized through a long-term time series of daily hydrological data and a sound methodology to determine the expected water flow at the potential site. It is, therefore, important that infrastructure plans incorporate climate risks [15]. ii) High capital costs are attributed to the long construction periods and high risks due to local geological conditions, flooding, and many civil works involved. Other costs are associated with environmental/social considerations, especially investment in communications and mitigation measures for environmental and sustainability. iii) The unpredictable power output is due to the stochastic nature of water flows, particularly for run-off river plants. iv) There is occasional resistance from the communities over any interference with river flow.

The resistance may be triggered by the need to preserve natural watercourses for aesthetic and recreational reasons as well as justifiable concerns to sectors of society unduly threatened or affected by large dams. Reaction may be severe, particularly in regions where livelihood and life depend on effectively providing a greatly increased water supply. In addition, there is the concern of great potential for a catastrophic accident with large loss of life and property damage in the event that the dam fails. Such tragedy was experienced in Kenya in 2018, when the Solai dam burst its banks, killing 47 people and damaging property and agricultural land. v) Dams can be vulnerable to acts of war or terrorism. Licensing for the construction of dams should be based on various approved fool proof technical. vi) Competition for water use, with needs for drinking water and agricultural irrigation contesting with its use in hydro plants. As [10] reported, wars over water will replace wars over oil as a major source of global conflict. Such conflict has been witnessed in the Nile River, where various countries have contested ownership and use of Nile waters.

The need to enter into binding agreements over ownership and utilization of shared resources emerges. vii) Lack of a proper policy framework to encourage Independent Power Producers (IPPs) and complicated licensing and concession systems to access water rights and leaveways for power production hampers the development of small-scale hydropower plants. Current national policy has over-emphasized large-scale hydropower development at the expense of small-scale hydro. Further, no national plans for optimizing hydropower plant operations under alternative future flow regimes exist. In addition, the country lacks the necessary infrastructure for the production and installation of micro hydro systems or the repair of systems [5].

4.3.3. Future Trends

The technical, economic, and environmental benefits of hydropower make it an important contributor to Kenya's future energy mix. Hydropower systems offer extremely low operating costs and long operating lifespans, which makes them viable substitutes for the cost-intensive energy system.

A report by the International Finance Corporation (IFC) on hydropower indicates that hydro's technical potential is five times the current utilization rate, and the huge potential exists in developing countries (www.ifc.org). Kenya's drainage system consists of 5 major basins: the country's inland hydro resources, Lake Victoria, Rift Valley, Athi and coastal area, Tana River, Ewaso-Nyiro and North-Eastern. The total hydropower technical resource is estimated to be about 6 GW, comprising large hydro with a capacity of more than 10MW, with half this potential being attributed to small hydro. The hydro resources lie in areas of high domestic energy demand [4, 5]. Approximately 55 river sites have been identified as attractive commercial possibilities for mini and micro hydropower, with maximum mean capacities in the range of 50 kW to 700 kW. Other sights that hold potential for hydropower development have been identified, including Mt. Kenya, Nyambene, Aberdare and Mt. Elgon, Kisii highlands, Nandi hills, Cherangani hills, Kerio and Mau escarpments, and Shimba hills at the coast [5]. Studies have established that the total hydro capacity could drop in the future due to public concerns in many regions in the country and the unlikely lessening of regulatory or licensing provisions affecting hydroelectricity.

4.4. Wind Energy

4.4.1. Current Status of Utilisation

Thanks to its diverse topographical characteristics, differing surface areas and large freshwater lakes, Kenya has one of Africa's most abundant wind power potentials. The result of a study commissioned by the government of Kenya in 2013 showed that around 73% of the country has more than 6 m/s of annual mean wind speed at 100 meters above ground level [4]. The country has an installed wind capacity of 435.5MW (32). Lake Turkana Wind Power Project (LTWP), the Ngong Hills Wind Power, and Kipeto Wind Farm projects are the only wind farms presently connected to the national grid, with capacities of 310 MW, 25.5 MW and 100MW, respectively. The LTWP, with 365 wind turbines, each with a capacity of 850kW, is Africa's largest wind power plant, having achieved full commercial operation in March 2019 [5]. The Ministry of Energy and Petroleum recorded an output of 330.4MW of wind energy between 2013 and 2017[1]. About 80-100 small wind turbines (0.4 – 6 kW) have been installed to date. In the period between the year 2017 and 2022, wind contributed 16.22% to Kenya's energy mix. This was the highest recorded wind contribution, with an energy generated value of 2,052.26 GWh, as illustrated in Figure 2 (32).

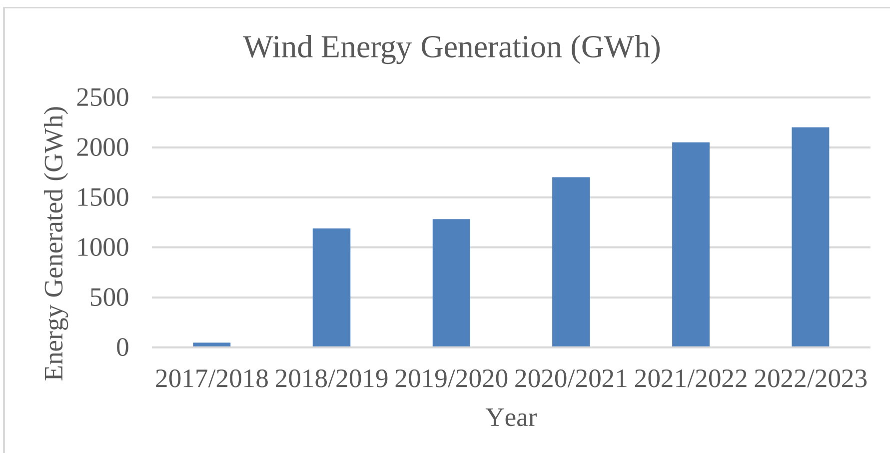

Fig. 2 Wind energy generated between 2017 and 2022 [32]

4.4.2. Challenges and Possible Mitigations

According to [1], the main issue affecting wind energy utilization is the limited knowledge of the Kenyan wind resource. The meteorological station's data are unreliable, and the information gathered is inadequate to give detailed resolutions due to the sparse station network. Modern measurement campaigns have started recently for investigating wind park locations. The intermittent nature of wind makes it difficult to provide consistent energy and guarantee supply during peak demand periods. High cost of land, speculation and agitation leads to higher capital costs for future projects and delayed implementation. Undertaking participatory feasibility studies and community relations exercises and ensuring valid land valuation by the National Land Commission (NLC) are possible mitigations. Further, government financial policies and changes in taxation may, in some cases, slow down the implementation of projects. It is important to develop a proactive approach to planning and forecasting while ensuring adequate stakeholder engagement.

Wind energy is low efficiency and does not blow at 100% all day. Therefore, the grid has to withstand its volatility. Cost, accessibility and rapid technological advancement are impediments to the development of wind energy. The high initial cost of technologies is difficult for many investors to access. The ultimate solution to this challenge is to enhance local manufacturing through incentivisation and public-private partnerships. Fortunately for Kenya, two manufacturers, Bobs Harries Engineering Limited (BHEL**)** and Craftskills Enterprises, have pioneered the local manufacture of wind pumps and wind generators and are providing local energy solutions for off-grid households and institutions [12].

4.4.3. Future Trends

Kenya has excellent wind regime areas due to the presence of the Rift Valley and various mountain and highland areas. The North West of the country (Marsabit and Turkana districts) and the edges of the Rift Valley are the two large windiest areas with average wind speeds above 9 m/s at 50 m high, while the coast has about 5-7 m/s at 50 m high. Generally, about 25% of the country is compatible with current wind technology [12]. The strategic plan for the country is to generate 800MW by 2022 and 2GW by 2030 from Wind Power. Kenya has promising wind power potential estimated at 22,476 TWh/year in the windiest areas. The Kipeto project (Kajiado), which will supply 100MW, will be the second largest [5].

4.5. Solar Energy

4.5.1. Current Status of Utilisation

Kenya has high solar energy potential with 4-6kWh/m^2/day of insolation and an average of 5-7 peak sunshine hours throughout the year, owing to its location near the equator. Majority of the northern and northeastern regions are solar hot spots [5 & 4]. Solar energy represents 1.8 % of the total energy demand in Kenya, with about 1.2% of households using solar energy, mainly for lighting and charging appliances [4]. Inspite the demonstrated large potential of PV utilization, current exploitation is limited, and projections show a modest growth [16]. An estimated 200,000 rural households have solar home systems. Between the 2013 and 2017 planning period, a total of 1400 Solar PV systems were installed in 64 public institutions, including secondary schools and health facilities [1]. As of June 2022, the government of Kenya had licensed solar photovoltaic systems with a combined capacity of 23.99 MW. The significant growth in the utilization of solar photovoltaic (PV) systems in Kenya is attributed to a global reduction in the cost of solar systems and the government's efforts to develop and enforce facilitative regulations. The installed solar systems include utility-scale projects, commercial and industrial solar PV systems, solar water pumping systems, mini-grids, solar streetlights, solar home systems and consumer devices.

Presently, Kenya has four (4) utility-scale solar photovoltaic plants with a combined installed capacity of 170 MW. These are Garissa Solar Power (50MW), Selenkei solar (40MW), Cedate solar (40MW) and Malindi solar (40MW). In the period between 2017 and 2022, these plants contributed 2.47 % to Kenya's energy mix. Figure 3 shows the contribution of solar photovoltaic systems to the national grid between 2017 and 2022. The exponential increase in solar energy generated between 2020/2021 and 2021/2022 is attributed to the commissioning of the Selenkei, Cedate and Malindi solar plants [32].

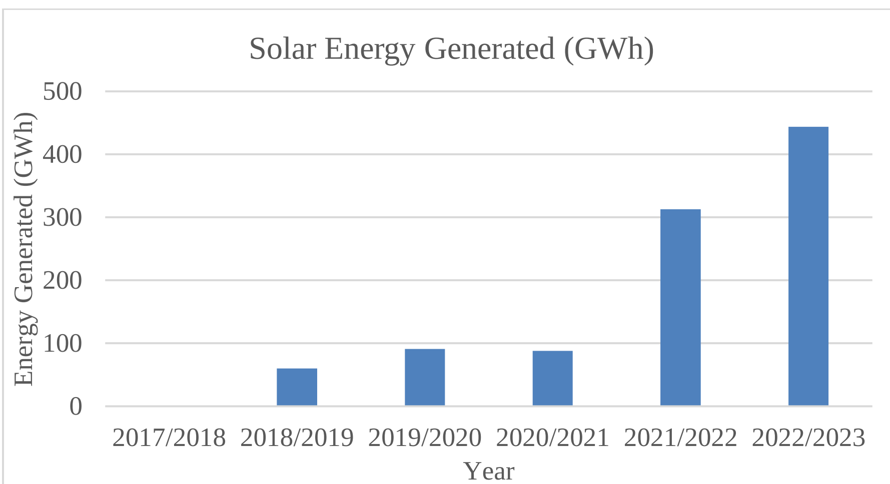

Fig. 3 Solar energy generated between 2017 and 2022 [32]

There has been a notable consistent demand for Solar Water Heaters (SWHs) among a few households and institutional groups such as hotels and schools. Solar driers are widely used for processing agricultural produce. A number of NGOs and churches have attempted to introduce solar cookers to rural groups in various parts of the country for cooking and water pasteurisation. The same has been particularly promoted in refugee camps and other areas with acute fuelwood shortages. Other promoters are donor community and development partners. Notably, the GIZ project promotion of Solar-Hybrid Mini-Grids (GIZ ProSolar) and the Talek. Power mini-grid pilot projects were set up in close cooperation with the Narok County Government and the German Agro Action [1].

4.5.2. Challenges and Possible Mitigations

The barriers to solar energy exploitation are technological, economic, institutional and policy-related. The technological barriers range from the quality of PV systems, lack of adequate knowledge, which may result in improper usage and inability to maintain the systems, to lack of energy storage systems [16]. While battery storage solutions have been widely used, their initial cost is prohibitive. Hybrid systems, combining solar PV with hydropower as a viable alternative to battery, could be explored. Building local capacity to manufacture solar systems could ease access and increase adoption. Among the government's interventions towards making the technology more attractive was establishing PV and Solar Water Heater regulations through the Energy Regulatory Commission. The other challenge is the lack of capacity or skilled personnel to install solar systems, especially in rural areas. Ultimately, the need for the country to have a well-trained workforce competent in handling solar PV-related technological issues is dire. An advanced training course for solar technicians has been developed, comprisings hands-on training at a 10kW solar-hybrid demonstration system at Strathmore University. Others are practical handbooks developed in collaboration with government institutions [5]. The economic barrier to PV integration is high capital and the inability to access funding from financial institutions for solar investments [16]). The government of Kenya, private companies, and NGOs have provided incentives, which have caused prices to drop significantly. Institutional barriers range from the long and complicated licensing process to fragmented and minimal research and development among the academia, training and research institutions. There is a need for synergy among these institutions. Weak linkages between academia and industry hinder the commercialization of solar technologies. Close linkages and partnerships need to be forged for a seamless technology transfer. An enabling policy framework devoid of inconsistencies is important for accelerated adoption. Recently, Kenya has instituted policies meant to increase the integration of PV [14].

4.5.3. Future Trends

There is no doubt that in the energy economy of the 21st century, solar energy will play an increasingly important role as the world, with its increasing population, struggles to achieve a truly sustainable energy society. According to Ravirajan [17], solar energy has been identified as one of the promising renewable energy sources that has the potential to meet the future energy demand in developing countries. There are about 4 million households in rural Kenya, which presents a vast potential for this virtually untapped technology, and the off-grid market is estimated to be over 40MW. The Ministry of Energy and Petroleum has been actively promoting the use of solar energy for off-grid electrification in public institutions. Grid-connected PV systems covering an area of 15-20 km^2 (3% of the Nairobi area) are projected to provide 3801 GWh of electrical energy a year. The government offers substantial incentives to strengthen solar PV installations due to long-term environmental and economic advantages. Removal of VAT on solar products, totaling 16%, was aimed at increasing product uptake, particularly in the off-grid arena. With access to loans and fee-for-service arrangements, estimates suggest that the Solar Home Systems market could reach up to 50% or more of the un-electrified rural homes. [14].

4.6. Nuclear Energy

4.6.1. Current Status of Utilisation

Nuclear energy is obtained through controlled nuclear fission reactions of uranium atoms in a nuclear plant reactor. Kenya targeted diversifying the country's energy mix to improve its electricity generation capacity through nuclear energy. The Third Medium Plan identified various priorities for nuclear energy as the development of legislative and regulatory frameworks; site identification for the nuclear power plants; continued capacity building through national programme and international partnerships, public education and advocacy; and establishment of a Research and Development Institute for nuclear energy [1]. The Energy Act of 2019 established the Nuclear Power and Energy Agency, the nuclear energy programme implementing organization [18]. The Agency has developed a 15-year strategic plan to implement Kenya's Nuclear Power Programme. The process of educating the public on nuclear power generation in various countries is ongoing. Preparatory activities undertaken include pre-feasibility study, human resource development, electric grid study, strategic environmental assessment, regulatory framework development and public engagement. The plan is to develop the first 1,000MW nuclear energy plant and connect it to the national transmission and distribution grid for enhanced energy generation.

4.6.2. Challenges and Possible Mitigations

Energy from nuclear fission is likely the most contentious and the most feared of all the energy sources. The main concerns associated with nuclear energy are related to safety and health. The possibility of a catastrophic accident involving a nuclear reactor, disposal of radioactive waste products from a reactor, nuclear reactor safety, the effect of radiation on human health, nuclear weapon proliferation, and the possibility that a rogue nation or a terrorist group could acquire technology and components to build a nuclear weapon and decommissioning of a nuclear energy plant are some of the concerns around nuclear energy [10]. Lack of trained manpower to operate and maintain a nuclear power plant in Kenya is also a major challenge. Consequently, through the Nuclear Power Agency (NuPEA), the government rolled out annual training programmes targeting Kenyans in various fields to build adequate capacity for the country's nuclear power programme. Further, Kenya has signed multiple memorandums of understanding with various countries that are more established in nuclear energy technology (www.nupea, go.ke).

4.6.3. Future Trends

Due to the controversy behind nuclear power reactors, the future use of nuclear energy remains uncertain, despite the undeniable advantage of not releasing carbon dioxide emissions. This makes nuclear energy a real option where there is concern for significant cuts in carbon dioxide emissions while maintaining high energy production and consumption levels. As a result, new reactor designs are being developed that are “inherently safe.” Some designs are also based on using thorium as the fuel to avoid making and handling weapons-grade uranium and plutonium [10]. Since nuclear projects are established pursuant to a declared national policy, public engagement and information will help people deal with the fears associated with nuclear power generation.

The Least Cost Power Development Plan (LCPDP) and the Energy Bill 2016 recognized the need to include nuclear energy in Kenya’s energy mix. Kenya was slated to have installed a capacity of 4 GW of nuclear energy, generating about 19% of the country's energy needs by 2030 [19]. In 2017, the Kenya Nuclear Electrification Board (KNEB) estimated that a 1,000 MW nuclear plant could be operational by 2027 at a cost estimate of Ksh500 billion to 600 billion ($5-$6 billion. Despite the government’s commitment to establishing the nuclear power plant, serious doubts have been expressed concerning cost and safety.

4.7. Coal Energy

4.7.1. Current Status of Utilisation

Coal is vital in power generation, steam production, and steel manufacturing processes. However, it has a limited role in residential, commercial, and transportation applications. There are no known reserves of coal that can be used for commercial purposes in Kenya, and meeting all its requirements has been through importation. Among the targets on coal under the Ministry of Energy and Petroleum Strategic Plan 2013-2017 was the development of 1,920MW of coal energy [1]. During this period, a Public Private Agreement for developing a 981.5MW coal plant in Lamu was signed, and exploration was carried out in the Mui Basin Districts of Kitui, Mwingi and Taru Basin in Kwale District. From 2007, 10 wells were drilled in the Mui Basin with positive findings suggesting the potential presence of industrial volumes of gas. In Lamu, a 1050 MW coal-fired power generating plant was proposed as part of the Lamu Port-Southern Sudan-Ethiopia Transport Corridor (LAPSSET) project [4].

4.7.2. Challenges and Possible Mitigations

Coal is the most polluting fossil fuel, while greenhouse gas emissions from burning coal are a major contributor to climate change. Coal fuel produces the highest CO_2 emissions per unit of energy of any of the fossil fuels and has the highest sulfur content, which produces Sulfur oxides (SOx). Sulfur oxides are responsible for acid rain, which adversely affects the environment. Further, coal is the only fossil fuel that produces significant quantities of ash when burned, and its extraction causes adverse environmental disruption. Some of the possible solutions to the coal problems include pre-combustion strategies of coal cleaning, switching to a fuel of lower sulfur content, or switching to a different kind of fuel, as well as the post-combustion strategy of flue gas desulfurization [10]. The call to phase out coal production in the energy mix has lately become popular across the globe. Kenya has yet to roll out the development of coal plants despite having identified potential sites.

4.7.3. Future Trends

Many coal mines have been closed or might expect closure in the not-distant future as debate on climate targets rages on. During the 26th conference of the parties (COP26) to the United Nations Framework Convention on Climate Change (UNFCCC), there were pledges and pronouncements by some countries to phase out coal-fueled power generation and stop building new plants in an effort to achieve globally agreed climate targets. European Union and 45 other countries pledged to “accelerate a transition away from unabated coal power generation at least in the 2030s. “The end of coal is in sight’’ were the words of British business and energy secretary Kwasi Kwarteng, as reported by the Centre for Strategic and International Studies (CSIS) (www.csis.org/analysis/battle-coal-cop26). According to [14], the strategic plan is to reduce the quantities of imported coal for industrial use by 40% by 2022 and roll out public education and awareness on clean coal Technologies. As a result of the pledges made during the COP 26 convention in which Kenya was highly represented, only time will tell the strategic direction that the country is likely to take in the future. The future of coal, therefore, awaits presidential pronouncements and requisite legislation.

4.8. Petroleum Energy

4.8.1. Current Status of Utilisation

Petroleum is one of the major energy resources, that collectively comprise fossil fuels and is most important for modern society [10]. Kenya does not have any oil reserves but depends heavily on imported petroleum products, whether processed or crude, for its energy needs. Petroleum comprises 21% of Kenya’s primary energy sources and has, over the years, accounted for about 80% of the country’s commercial energy supply. The bulk of petroleum products is consumed in manufacturing, transport, commercial, residential, lighting and power generation. The petroleum sector contributes over 20% of the Gross National Product [20]. The domestic demand for various petroleum fuels, on average, is 2.5 million tonnes per year [21]. This demand is projected to rise by an average of 3.1% per annum till the year 2030. Kenya Petroleum Refineries (KPRL) has a limited capacity and can supply about 45% of the Kenyan market's fuel demand. The balance (55%) comprises imports of already refined Petroleum products [22]. The scenario for petroleum import and export for the period between 2008 and 2018 is presented in Figure 4.

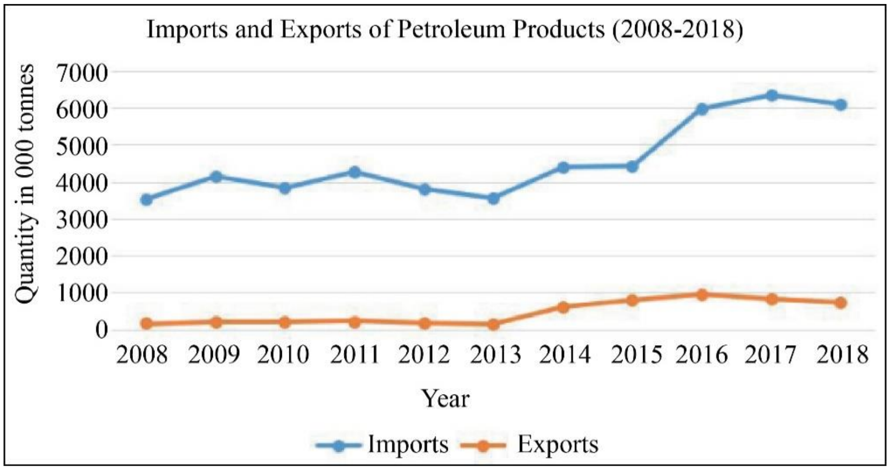

Fig. 4 Quantity of petroleum imports and exports. source: [18, p. 20]

The total quantity of petroleum products imported into the country increased from 3,976.3 thousand tonnes in 2008 to 6,114.4 thousand tonnes in 2018, representing a growth rate of 53.8%. The country's net imports for 2019 were 5.682 million tonnes [20]. The quantity of petroleum products imported into the country for local use increased from 4,994,577m^3 in the financial year 2020/2021 to 5,539,884m^3 in the financial year 2021/2022. Imports destined for the transit market reduced from 3,739,033.84m^3 to 3,052,312m^3. Figure 5 gives a summary of the trend in petroleum product imports by market for the period under review [32].

The total domestic demand for petroleum products imported increased by 4.55% per cent to 5,738,216.27 m^3 in the financial year 2021/2022. This was partly attributed to a 30.18% increase in the demand for jet fuel as a result of the opening up of the economy and resumption of air travel across the world post covid. Diesel was the most consumed petroleum product with 2,717,077.21 Million cubic meters sold, followed by super petrol with an estimated consumption of 2,182,665.51 m^3. This is due to the high number of diesel engine-driven vehicles, especially in the public transport sector.

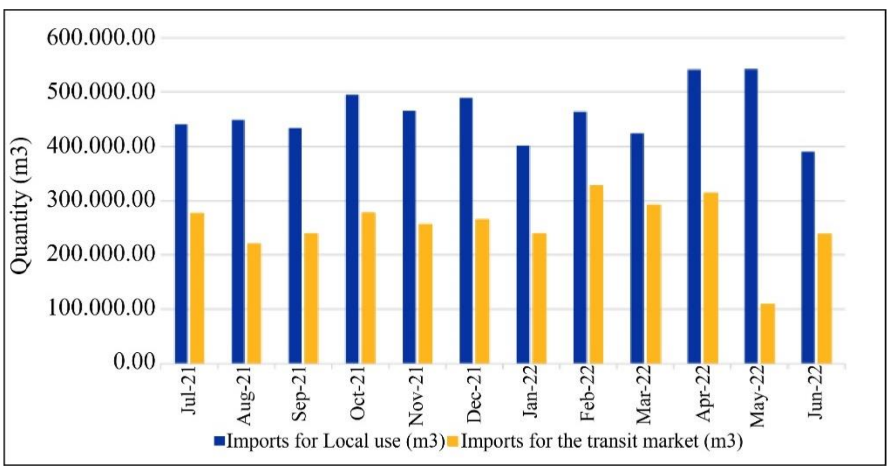

Fig. 5 Trend in quantity of petroleum imports for local use against that meant for the transit market [32]

Liquidified Petroleum Gas (LPG), which is widely used in the country, is manufactured at Kenya Petroleum Refineries Limited. Currently, 92% of all households in Kenya use Kerosene both for lighting and cooking. Jet/turbo fuels are market-specific commodities with an annual usage of 340,000 tonnes [4].

4.8.2. Challenges and Possible Mitigations

The challenges of petroleum and petroleum products can be viewed from 4 broad perspectives, namely: a) lifetime estimate/reserves, b) environmental, c) economics and d) geopolitics. Petroleum is a finite resource whose limits of available reserves are diminishing at a faster rate than that of discovery and exploration. Though it is not certain the amount of reserves, predictions using some 2012 data for oil in the lifetime equation indicated that reserves are 1478 trillion barrels against annual global consumption of about 33 billion barrels [10]. Reducing oil consumption can be achieved by efficient usage, conservation or substitution with alternative energy sources. On the other hand, the development of advanced technologies for exploration and production may result in the discovery of more oil reserves in future. Sadly, Kenya has no system for increasing the volume of oil imports or storing them in the wake of an oil supply disaster. However, the Energy Act of 2007 requires the Ministry of Energy to institute modalities for creating strategic stocks [1]. Burning fossil fuels may have long-term effects on the environment, most notably through global climate change. Carbon dioxide, the main pollutant of petroleum products, is responsible for global warming. Further, petroleum products contain nitrogen and sulfur. These 2 elements form combustion products SOx and NOx, which are of great concern because of their effects on the environment through the formation of acid rain [10]. First, the solution to this problem is to reduce energy consumption substantially and enhance energy efficiency. This reduction means burning less fuel and, hence, less pollutant emission. Secondly, it is shifting to alternative clean, renewable energy sources of low carbon, sulfur, and nitrogen, such as solar, wind, biomass, and nuclear energy, where possible. Lastly, it reduces or removes potential pollutants before they are released into the environment. Kenya has a roadmap for renewable energy development and energy efficiency strategies in place. The strategies aim at lowering the cost of fuel as well as mitigating the effects of climate change brought about by the consumption of petroleum products [1].

Petroleum-based accidents are a possible occurrence at various stages of handling petroleum products. Instances of oil leakage through the pipeline or spillage during transportation have been reported. While some have been easily managed, others have been catastrophic, causing loss of lives. Such tragedy was experienced in Kenya in the year 2009, at Sachagwan area in Nakuru County, where 78 locals were burnt in a fire tragedy, as they siphoned fuel after an oil tanker overturned. Consequently, the Energy Act 2019 outlines the requirements for compliance with environmental, health and safety standards. The act emphasises the need for petroleum product traders to comply with Kenya Standards and any other standards approved by the Energy Commission from time to time. Further, the act provides that any trader engaged in transporting petroleum and petroleum products shall have an oil clean-up plan in compliance with the national standards [23]. Variability and uncertainty of petroleum prices affect all sectors of the economy with the pressure to import petroleum products, leading to the growth of external debts. As of 2007, Kenya spent over 40% of its foreign exchange earnings on importing crude oil and other petroleum products [24]. The other challenge is associated with an uncoordinated regulatory approach for the smooth and efficient administration of the petroleum industry. This fragmentation presents a need to review the restrictive Trade Practices, Monopolies and Price Control Act (CAP 504, Laws of Kenya). The lack of a supportive and enabling environment results in product dumping, product adulteration, and illegal, sub-standard fuel sites, which necessitates the need to institutionalize free market functions to promote standards and effective regulation. Further, petroleum has become a tool of geopolitics, commonly referred to as the “oil weapon’’. It is important to note that unstable political regimes and volatile relationships between petroleum-exporting countries and importing countries have a major effect on the supply and price of petroleum products [10].

4.8.3. Future Trends

Kenya has made notable strides towards securing energy supply in the country. According to the National Oil Company of Kenya (NOCK), petroleum exploration in Kenya began in the 1950s within the Lamu Basin. However, the first commercially viable oil discovery was made in 2012 in the Tertiary Rift, followed by significant gas discoveries in the Lamu basin. Over 86 wells have been drilled to date, with a majority within the Tertiary Rift. An estimated four billion barrels of crude oil reserves were discovered in Turkana, Lokichar sub-basin by Tullow Plc Company and its partners, with recovery oil estimated at 750 million barrels (www. Nationaloil.com). In spite of confirmations of these oil reserves, their commercial viability is yet to be determined and exploited. The ultimate plan for the government of Kenya, under the Third Medium Term Plan, is to promote the development of renewable energy with the aim of lessening dependence on imported petroleum products. Waiver of import taxes from LPG cylinders came in hard to make affordable for consumers. Moreover, the government envisaged the construction of a Liquefied Petroleum Gas (LPG) handling facility in Mombasa to boost supply in the country and the Great Lakes region. In addition, the government is to commence a public-private partnership to construct an inland depot and LPG distribution and filling depots in Athi River, Eldoret, Nakuru, Kisumu and Sagana [1].

4.9. Different Types of Biomass Energy - Methanol, Ethanol, Biodiesel, Methane and Hydrogen

4.9.1 Current Status of Utilisation

Methanol, Ethanol, Biodiesel, Methane and Hydrogen are renewable energy sources of less, or zero polluting effect on the environment. According to [25], an extra 200 million people worldwide are projected to rely on biomass for their cooking and heating needs by 2030. Switching to and accessing cleaner fuels is one strategy for dealing with the problems of the health effects caused by the smoke and other pollutants released in enclosed cooking areas. Promoting the development of these resources in Kenya is a mandate of the Cabinet Secretary in the Ministry of Energy and Petroleum.

The Energy Act 2019 established an inter-ministerial committee known as the Renewable Energy Resource Advisory Committee to advise the cabinet secretary on matters of renewable energy resources. Among the strategic programmes outlined in the MoEP strategic plan 2013-2017 is the promotion of the uptake of non-conventional renewable energy technologies, among them bio-diesel and bio-ethanol. The target is to develop 150MW in 3 years or 50MW annually of electrical capacity from renewable energy resources [1]. In addition, the government established a Bioenergy Strategy 2020-2027. The strategy sets guidelines and approaches and identifies strategic interventions to promote the development and sustainable utilisation of bioenergy resources in Kenya over the period between 2020-2027[14].

This strategy incorporates the recommendations of the roadmap for biofuels in Kenya report commissioned by the German Technical Cooperation Kenya and Ministry of Agriculture [26] and the Kenya Ethanol Cooking Master Plan 2021. Kenya has a high potential for generating electricity from biomass sources from agricultural wastes, the sugar cane, sisal, timber (sawdust) and meat industries. The development of a bioenergy industry has the potential to improve energy security, reduce energy imports, and promote the agricultural and forestry sectors by adding value to traditional crops.

The removal of excise duty on ethanol (now zero-rated) and lowering of duty for clean cooking stoves demonstrated clearly the government’s dedication to efficient utilisation of bioenergy for cooking. Cookstove standards have been developed inorder to promote efficient utilisation of biomass through the Kenya Bureau of Standards (KEBS). Clean Cooking Laboratory has been established at the Kenya Industrial Research and Development Institute (KIRDI) to facilitate the implementation of the standards [27].

4.9.2. Challenges and Possible Mitigations

Among the challenges with biomass feedstock are the capacity to endanger ecosystems and biodiversity, especially when being cultivated in monocultures, water pollution due to the use of agrochemicals, and the release of polluting emissions. Burning of biomass produces substances that could lead to air pollution, such as carbon monoxide, nitrogen oxides, and particulates such as soot and ashes [10]. The other challenge is the demand for large parcels of land. The amount of available land has to be considered when assessing the ultimate potential of biomass fuels on a global scale.

Important to consider as well is the trade-off between the uses of land for food crops versus its use for energy crops. Therefore, it is essential to find a balance between opportunity maximization and risk minimization, for which a well-defined regulatory framework is paramount. On the other hand, the use of municipal waste presents both economic and environmental benefits.

Despite traditional biomass dominating Kenya's energy landscape, little budget is provided for research, development and dissemination of bioenergy resources and technologies. Therefore, It is important that the country purposefully invests in developing bioenergy sources [14].

4.9.3. Future Trends

Methanol

Methanol is produced on a large scale using natural gas. Biomass might prove difficult to compete with natural gas as a feedstock for methanol synthesis without substantial tax incentives. Kenya has not prioritized methanol production in the bioenergy strategy, and it meets all its commercial methanol requirements through importation. However, a large potential exists for producing methanol from Municipal Solid Waste (MSW), agricultural waste and forestry residues. Several factors limit the use of methanol as a fuel. i) Low energy balance for biomass conversion. The heating value of methanol, on a volumetric basis, is about 21 MJ/L. Methanol provides only about 58% of the energy as a comparable volume of gasoline or 58% of the fuel economy. The low fuel economy translates to frequent fueling and high cost of fuel. ii) Methanol is hazardous, and its accidental ingestion can lead to blindness or death. Further, methanol has been blamed for causing deaths after unsuspecting customers consume alcoholic drinks laced with toxic chemicals. Such cases have been reported frequently in Kenya, with the latest being the Subukia one that killed five people after consuming an illicit brew suspected of containing methanol. iii) Since methanol burns with a nearly colorless flame, accidental methanol flame might be hard to see. iv) A vehicle set up to burn gasoline would require adjusting the fuel injection system because of the different air-to-fuel ratio needed to burn methanol. v) Methanol is soluble in water; thus, there is a high possibility of water blending into a methanol fuel, causing problems in running the engine [10].

Ethanol

Ethanol, also known as ethyl alcohol, is a liquid fuel produced from various sugars and starch-containing feedstock. Cellulose from biomass waste, woody fibres, and grass is also a source of ethanol [26]. Kenya has recognized the value of investing in bioethanol production for blending, which can be used in the transportation sector. Currently, ethanol is exclusively produced from molasses feedstock, a by-product of sugar production. About 1.2 million litres of ethanol cooking fuel is produced annually. The demand for ethanol as a primary cooking fuel is projected to increase over 10 years. In order to capture variability in demand assumptions, 3 scenarios were created. Scenario 1 is a low case, whose demand is projected to rise from 8 million in year 1 to 115 million in year 10. Scenario 2 is a base case whose demand is expected to rise from 16 million in year 1 to 192 million in year 10. Scenario 3 is high, with demand rising from 24 million in year 1 to 268 million in year 10 [28]. A key constraint to ethanol production is the national shortage of molasses caused by the inefficient performance of public mills and the reduction of sugarcane farming. Most state-owned sugar companies have faced operational challenges and since suspended production; hence, the current major sugar producers are private-sector companies [28]. These companies and their production levels are shown in Table 5.

Table 5. Ethanol-producing companies and their quantity of production [28, p.27].

Sugar Company	2018 Quantity of production (MT)	% Production
Mumias Sugar Company Ltd	88,201	1.90
West Kenya Sugar Company Ltd	925,894	19.91
Butali Sugar Mills Ltd	707,301	15.21
Kibos Sugar &Allied Companies	83,2272	17.90
Sukari Industries Ltd	518,534	11.15
Transmara Sugar Company Ltd	730,632	15.71
Kwale International Sugar	172,312	3.71
Nzoia Sugar Company	393,118	8.45
Chemelil Sugar Company	282,052	6.07
Total	**4,650,316**	

West Kenya Sugar Company Limited had the highest production at 19.1 %, while Mumias Sugar Company had the least production at 3.71%. The projected increase in demand for Ethanol Cooking Fuels (ECF) presents a great opportunity for Kenyan farmers, ethanol producers, and distributors. The availability and affordability of ethanol, which is enabled by sufficient domestic production and supply chain development, as well as greater awareness of the health and environmental benefits of ethanol, is likely to drive the demand [28]. Production of cellulosic ethanol instead of starch-based ethanol, ethanol oil blends (gasohol) that are compatible with existing engines, and its use as an oxygenate and octane booster would significantly boost ethanol. With demand projected to be 192 million litres in 2030, ethanol has the potential to generate significant income for the economy [14].

Biodiesel

Biodiesel is a vegetable oil or animal fat-based diesel fuel. Possible oil crops for biodiesel include castor, croton, sunflower, jatropha, and coconut, among others. The fuel can also be made from waste cooking oils or animal waste. Plant oils are, in principle, renewable carbon dioxide neutral, and the by-product of plant oil production is a high-protein "meal" that can be used as cattle feed. A key advantage of biodiesel is the high oxygen content, which aids in the completion of fuel combustion and leads to lower emissions of particulate air pollutants, carbon monoxide, and hydrocarbons. Further, biodiesel is blended with traditional diesel fuel or burned in its pure form in ordinary compression ignition engines without the need for engine modification [14]. According to a report on the roadmap to biofuels in Kenya, commissioned by GTZ in 2008, biodiesel production is at an early stage, with little research done in the sector. However, a flurry of activities among government agencies, Non Governmental Organisations (NGOs), and the private sector indicate great potential [26]. The Biodiesel Association of Kenya was formed in 2008 and is comprised of major stakeholders to promote and coordinate activities related to biodiesel. Blending biodiesel with traditional diesel has produced blends ranging from 1% biodiesel and 99% diesel (B1) to 25% biodiesel and 75% diesel (B25). One of the successful biodiesel plants in Kenya is Castor Seed Kenya Ltd, with approximately 700 acres of castor seed under cultivation in Kenya's coastal region and subcontracting about 400 farmers. From a global perspective, biodiesel is anticipated to form 70% of transport fuel demand by 2040. A consistent rise in diesel car markets is highly likely to trigger a high demand for biodiesel [29].

Methane

Biogas is produced through the anaerobic fermentation of biomass and other organic waste. This process may occur naturally or by deliberate intent in equipment designed for the purpose whose reaction is facilitated by anaerobic bacteria. The gaseous fuel produced by the anaerobic digestion of wastes, referred to as biogas, contains methane as the main component. Kenya has approximately 21,000 biogas digesters distributed through efforts from both the government and private sector. The use of biogas for cooking is projected to reach 0.8% by 2030, while electricity generation from biogas will be at 0.07% of the renewable energy mix. A biofuel plant in Naivasha, producing 2 MW of power, is a grid-connected biogas plant utilising flower waste as feedstock. For each biogas unit, direct financial savings are estimated at USD 204 per annum [14]. One of the main challenges of methane is leaking out of landfills. Methane is a more potent greenhouse gas than carbon dioxide and is flammable. In some concentrations, methane/air mixtures are explosive.

The technical potential for biogas in Kenya has been estimated at 320,000 households. A feasibility study on biogas has established that there is a high potential to construct 6,500 biogas digesters annually in Kenya and that the country has the potential to establish 2.3 million digesters [14]. Most digestion systems installed are family-sized units to help meet the cooking and heating needs of small rural communities. Over 100 million people in the rural settlements currently cook with biogas. Biogas-based electricity generation potential has been identified in municipal waste, sisal and coffee production and is estimated at 29-131 MW. The government has proposed to install 20,000 biogas units at the household level. These units will enable dairy farming households to realise USD 61.2 million in cost savings over the 15-year lifetime of these units. The units will also save 8.8 million hours of women's time each year, thus enabling them to use their time to engage in other economic empowerment and personal development activities. Biogas promotion will also reduce fuelwood and charcoal use, with the installation of 20,000 units reducing an estimated 1.7 million m^3 of fuelwood use over a 10-year period [5]. The government has continually undertaken several initiatives to develop biogas in the country. Other government initiatives to develop biogas projects include programmes to construct bio-digesters in several areas for use as demonstration and training centers. The private sector has also been running programmes to establish bio-digesters across the country.

Hydrogen

Hydrogen is produced through gasification of biomass materials. Some bacteria can produce hydrogen directly from biomass under anaerobic conditions. Hydrogen combustion produces only water as a by-product and can be considered non-polluting, and its use is suitable for fuel cells [10]. Kenya has no data on the current use of hydrogen in the energy sector. The main challenges that hinder the utilisation of hydrogen are cost, efficiency and storage. Liquefying hydrogen at atmospheric pressure requires cooling to –253°C (20 K). Storing compressed gaseous hydrogen requires very strong high-pressure containers, which are likely to be very heavy and add substantially to the vehicle's weight and easily leak. Fuel cells hold the key to hydrogen's future as a large-scale energy resource. In spite of this form of energy gaining traction in parts of the world, Kenya has not demonstrated any plans for production except for studies on its generation.

5. Discussions

5.1. Policy Interventions

How Kenya plans to meet the energy needs of a young, fast-growing, and increasing population is crucial for the future of the economy and energy. Demographic changes will be the main drivers for economic growth, infrastructure development and, in turn, energy demand [25]. Undoubtedly, a rise in population growth rate will result in an equivalent, if not higher, demand for energy. A critical task for policymakers is to address the persistent lack of access to electricity and clean cooking and the unreliability of the electricity supply.

The government has put in place the necessary policies and regulations for developing the energy sector. Key strategies outlined under the Third Medium Term Programme to enhance the developments include intensification of energy diversification that ensures cheaper power in the energy mix. The diversification enhances affordability, promotes the transition from traditional fuels to modern sources and accelerates the adoption of energy efficiency technologies. In addition, diversification promotes off-grid connectivity and boosts generation, transmission and distribution systems to upscale the availability of power that sustains demand. Through secure long-term tariffs and guaranteed access to the grid, private sector investment in renewable energy has increased. [1]. The Ministry of Energy and Petroleum is mandated to assess the country's energy situation and implement energy projects and programmes that guarantee sustainable development.

The renewable energy programmes may include renewable energy resources inventory and resource mapping, formulation of a national strategy for coordination of research in renewable energy, and promotion of appropriate local capacity for the manufacture, installation, maintenance, and operation of basic renewable technologies. Such will enhance the harnessing of opportunities offered under clean energy development mechanisms and a more focused focus on international cooperation, the development of renewable energy sources, and climate change [1]. Kenya Vision 2030, the country's development blueprint, outlines the strategies and priorities for developing the energy sector. Consequently, the Big Four Agenda has provided a roadmap for the energy sector, with the aim of propelling the country to a more secure and sustainable energy supply. The Energy Act 2006 provides that municipal solid waste, renewable energy sources, cogeneration for energy production, production and use of gasohol and biodiesel shall be promoted by the Ministry of Energy and the Rural Electrification Authority.

These, among other programs, have aided the government to keep track of the developmental milestones and have provided benchmarks against which targets are evaluated. The government and other stakeholders, including consumers, must, therefore, be deliberate in their efforts to conserve energy by adjusting consumption patterns and promoting energy efficiency and conservation through regulatory frameworks. Diversifying the energy mix and developing existing energy systems should be a deliberate effort for all stakeholders in the energy sector.

6. Conclusion

Kenya relies on natural resources in the generation of 60% of the primary demand for energy. The cooking fuel market is dominated by charcoal (14.6%), firewood (54.6%), Liquefied Petroleum Gas (13.4%) and kerosene (14%) as primary fuels. Further, the manufacturing and transport sectors are wholly dependent on fossil fuels, with the transport sector contributing approximately 25% of all energy-related CO_2 emissions [20]. Excess extraction of natural resources for energy supply results in degradation and loss of biodiversity, while firewood is a threat to life and the environment.

Balakrishnan et al. argued that using fossil fuels to supply energy is the most important cause of greenhouse gas emissions, which cause adverse environmental pollution [30]. Dependence on the importation of energy is burdensome to the gross domestic product of the country, and the environmental consequences are severe. Price volatility and unreliable supply of fossil fuels make them an unfavorable choice of energy. Renewable energy is an acceptable alternative to fossil fuels because it is clean and can be used in most parts of the world.

Currently, there is a wide variety of renewable energy sources, such as hydropower energy, wind energy, solar energy, and biomass energy [30]. In the future, geothermal energy will likely dominate the energy landscape in Kenya, followed closely by wind energy. This is a result of the Government's promotion of independent investment and introduction of a feed-in tariff (FiT). According to the World Economic Forum, there is a wind of change in the energy landscape, and more nations are committing to carbon-free energy generation. Improved governmental policy support for renewables also paves the way for continued global growth in the sector [31]. It is, therefore, evident that the exploitation of sustainable and renewable energy sources is inevitable. The development of hybrid technologies that combine both electric and gasoline drive systems, such as hybrid vehicles, will ultimately result in improved energy sustainability. Hybrid car technology has evolved to a point where commercial models are available from most major car companies and are increasingly being used by the public [10].

Inspite this development in hybrid technologies, Kenya has yet to fully embrace and adopt the technologies in the transport system. Rolling out of hybrid technologies requires a reliable and adequate electricity supply and infrastructure in strategic locations.

Further, the lack of requisite policies and regulations to provide authority, accountability and responsibility are key hindrances to adopting hybrid technologies [20]. Generally, the adoption of renewable energy is hampered by the lack of appropriate technologies and the high cost of them. Therefore, the government's main task is to make sustainable energy affordable for all and competitive with conventional sources for acceptability and adoption while developing the necessary legislation. The ultimate goal of the Kenyan government is to achieve universal access by 2030 by largely focusing on expanding rural energy access. Research, development and technology transfer on green technologies, development of specialized curriculums in energy technologies, with a focus on renewable sources by the academic institutions in collaboration with industrial partners, removing barriers to energy efficiency systems and energy management strategies need to be continuous, in order to attain self-reliance in the supply of sustainable energy.

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References

[1] Ministry of Energy and Petroleum, Strategic Plan 2018-2022, 2018. [Online]. Available: https://energy.go.ke/wp-content/uploads 2021/09/21/

[2] Kenya National Bureau of Statistics (KNBS), Population and Housing Census Report, 2019. [Online]. Available: https://www.knbs.or.ke/reports/kenya-census-2019/

[3] Public Policy Repository, National Energy Policy 2018, Ministry of Energy, Republic of Kenya, 2018. [Online]. Available: https://repository.kippra.or.ke/items/db1dd59c-a26b-41ec-8c24-0f1b3f46cf6b/

[4] Mohammed Takase, Rogers Kipkoech, and Paul Kwame Essandoh, "A Comprehensive Review of Energy Scenario and Sustainable Energy in Kenya," *Fuel Communications*, vol. 7, pp. 1-13, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] Suswatch-Kenya, Plan for 100% Renewable Energy Scenario in Kenya by 2050, 2020. [Online]. Available: https://www.suswatchkenya.org/wp-content/uploads/2020/09/100-Renewable-Energy-Plan-for-Kenya-by-2050-12-08-2020.pdf/

[6] Government of the Republic of Kenya, The Constitution of Kenya, 2010, 2010. [Online]. Available: http://www.parliament.go.ke/sites/default/files/2017-05/The_Constitution_of_Kenya_2010.pdf/

[7] Government of Republic of Kenya, Energy Act, No. 12 of 2006, 2006. [Online]. Available: https://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/EnergyAct_No12of2006.pdf/

[8] Johnstone Mwanthi, Wind Sector Prospectus-Kenya, Ministry of Energy, Republic of Kenya, 2013. Available: https://www.academia.edu/13989342/Wind Sector Prospectus Kenya/

[9] R. Fuller, and Lu Aye, "Human and Animal Power-The Forgotten Renewables," *Renewable Energy*, vol. 48, pp. 326-332, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[10] Harold H. Schobert, *Energy and Society- An Introduction*, 2nd ed., CRC Press, Boca Raton, pp. 1-720, 2014. [Google Scholar] [Publisher Link]

[11] Canan Dagdeviren, Zhou Li, and Zhong Lin Wang, "Energy Harvesting from the Animal/Human Body for Self-Powered Electronics," *Annual Review of Biomedical Engineering*, vol. 19, no. 1, pp. 85-10, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[12] J.K. Githiomi, and N. Oduor, "Strategies for Sustainable Wood fuel Production in Kenya," *International Journal of Applied Science and Technology*, vol. 2, no. 10, pp. 21-25, 2012. [Google Scholar] [Publisher Link]

[13] WANLEYS Consultancy Services, Analysis of Demand and Supply of Wood Products in Kenya, Ministry of Environment, Water and Natural Resources, 2013. [Online]. Available: https://www.scribd.com/document/411278222/Analysis-of-Demand-and-Supply-of-Wood-Products-in-Kenya/

[14] Ministry of Energy and Petroleum, Bioenergy Strategy 2020-2027, 2020. [Online]. Available: https://www.energy.go.ke/sites/default/files/KAWI/Other%20Downloads/Bioenergy-strategy-final-16112020sm.pdf/

[15] I. Yuksel, "Development of Hydropower: A Case Study in Developing Countries," *Energy Sources, Part B, Economics, Planning, and Policy*, vol. 2, no. 2, pp. 113-121, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[16] Dominic Samoita et al., "Barriers and Solutions for Increasing the P.A Integration of Solar Photovoltaic in Kenya's Electricity Mix," *Energies*, vol. 13, no. 20, pp. 1-17, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[17] P. Ravirajan, "Solar Energy for Sustainable Development in Developing Countries," *Ceylon Journal of Science*, vol. 46, no. 2, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[18] Energy & Petroleum Regulatory Authority, Energy & Petroleum Statistics Report, 2021. [Online]. Available: https://www.epra.go.ke/sites/default/files/2025-02/Energy%20%20Petroleum%20Statistics%20Report-2021.pdf/

[19] Government of Kenya, Kenya Vision 2030, Development Blue Print, 2007. [Online]. Available: https://vision2030.go.ke/

[20] Energy & Petroleum Regulatory Authority, Energy & Petroleum Statistics Report, 2020. [Online]. Available: https://www.epra.go.ke/sites/default/files/2025-02/Energy%20Statistics%20Report%202020.pdf/

[21] Johnson N. Munyua, and Mary Ragui, "Drivers of Instability in Prices of Petroleum Products in Kenya-Review Paper," *Prime Journal of Business Administration and Management (BAM)*, vol. 3, no. 3, pp. 919-926, 2013. [Google Scholar]

[22] D. Owiro et al., "*Situational Analysis of Energy Industry, Policy and Strategy for Kenya*," Institute of Economic Affairs, Report, pp. 1-77, 2015. [Google Scholar] [Publisher Link]

[23] Government of the Republic of Kenya, Kenya Gazette Supplement Acts, 2019, Special Issue, Government Printer, 2019. [Online]. Available: https://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/2019/EnergyAct__No.1of2019.PDF/

[24] Jorge Tenório Fernando, and Sergio Ricardo Siani, "Renewable Energy Sources in Developing Countries: Challenges and Opportunities for a Sustainable Development Agenda," *RISUS - Journal on Innovation and Sustainability*, vol. 7, no. 1, pp. 64-71, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[25] International Energy Agency, Kenya Energy outlook, Report, 2019. [Online]. Available: https://www.iea.org/articles/kenya-energy-outlook/

[26] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Ministry of Agriculture and Livestock Development, Roadmap to Biofuels in Kenya Opportunities and Obstacles, 2008. [Online]. Available: https://kenyaclimatedirectory.org/resources/673cbe5c61b97/

[27] Ministry of Energy, Kenya National Energy Efficiency and Conservation Strategy, 2020. [Online]. Available: https://www.energy.go.ke/sites/default/files/KAWI/Other%20Downloads/2020_06-Kenya-Strategy-EE_LOW-1-1.pdf/

[28] Ministry of Energy Kenya Ethanol Cooking Fuel Masterplan, 2021. [Online]. Available: https://southsouthnorth.org/wp-content/uploads/2021/07/ECF-Kenya-Masterplan-cover.pdf/

[29] Mohammed Takase et al., "Status of Biodiesel Research and Development in Kenya," *International Journal of Green Energy*, vol. 19, no. 5, pp. 499-508, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[30] P. Balakrishnan et al., "Current Status and Prospects of Renewable Energy-A Case Study," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 42, no. 21, pp. 2698-27036, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[31] Johnny Wood, "*Kenya is Aiming to be Powered Entirely by Green Energy by 2020*," World Economic Forum, Report, 2018. [Google Scholar] [Publisher Link]

[32] Energy & Petroleum Regulatory Authority, Energy & Petroleum Statistics Report, for the Financial Year Ended 30th June 2022, 2022. [Online]. Available: https://www.epra.go.ke/annual-reports/