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A Technical Review of Oil and Gas Infrastructure in Kenya - Progress and Challenges.

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Abstract

Infrastructure is the lifeblood of oil and gas operations. It entails an array of assets such as drilling rigs, production gathering units, separators, pipelines, terminals, refineries, storage plants, etc. Most of these facilities are complex engineering marvels yet costly industrial outfits. In as much as they yield massive economic yields, they are also loaded to capacity with numerous challenges. These facilities consume colossal capital investments. From upstream, and midstream to downstream oil and gas operations, utilizing these resources requires specialized manpower, equipment, and facilities. Since 2012, Kenya has had high hopes of joining the elite group of nations with oil and gas deposits. However, efficiently and effectively utilizing them is completely another obstacle that the nation must face. This study, therefore, aims to compartmentalize the existing oil and gas infrastructure in Kenya. It evaluates the facilities in the downstream, upstream and midstream sectors of the gas and oil industry's history, exploration, progress, and potential in the future. Additionally, it assesses the difficulties in facility setup, maintenance, and decommissioning.

Keywords: drilling rig, pipeline, refinery, terminal, depot, separators

1. INTRODUCTION

Modern oil and gas infrastructure is defined as facilities and assets used in the extraction, processing, refining storage, distribution, and transport of energy and its related resources, fuels, and products globally, [1]. According to [2], the gas and oil industry must invest roughly $500 billion annually due to the rising worldwide demand for energy. And with the onset of the current conflict in Russia and Ukraine, this demand will exacerbate even much more. This view is in line with the observations of [3] who suggests that the current clamor for energy transition still means billions in fossil fuel investment. With an earnest desire to change the economic standards of its populace, we seek to find out just how well prepared is the Kenyan gas and oil industry for the imminent windfall in gas and oil investments. Consequently, this essay aims to study the state of Kenya's existing oil and gas infrastructure from the country's independence in 1963 through April 2022, distill the available data on the same and drill into the root causes of the challenges it is facing. Summarily, it attempts to highlight the optimal measures that can catalyze the nation to position itself advantageously for the forthcoming energy demand.

1.1 Global Oil and Gas Infrastructure Developments

Operations involving gas and oil are vital to the world economy. For this to happen, these resources need facilities. Oil and gas facilities are durative and expensive. While some cost hundreds of millions of dollars, others stream into the billion-dollar horizon, with sub-components of engineering, procurement, construction, and commissioning. For instance, in the USA, the gas and oil infrastructure industry is predicted to exceed $80 billion by 2024, with the total investment is expected to shoot to as high as $1.34 trillion by 2035, [1]. The increasing world population, transformative middle-class lifestyles, snowballing

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campaign of eliminating energy inequality, short-sighted persistent calls for a reduction in fossil fuel use, and easy access to information and technology are the driving momentum in the explosion of increased energy infrastructure investments. Oil and gas facilities are usually enormous and outstanding. One unique feature of these industrial icons is their ability to transcend political jurisdictions and possess an aura of distinctive economic landmarks. Due to the finite nature of fossil fuels and the enormous capital investments required for any oil and gas infrastructure, risk analysis and detailed optimized planning are now part and parcel of their development. Even though scholars hold differing views on the approaches needed for the optimization and risk management of the entire process, a majority concur that mathematical modeling, innovation, and programming of this process [4],[5] coupled with sensitivity analyses should be the order of the day for any major oil and gas project. In this essay, we will discuss the current developments in the downstream middle, and upstream components of the gas and oil infrastructure in Kenya.

1.2 Oil and Gas Infrastructure Developments in Kenya

Since 2012, successful exploration and appraisal drilling operations in Kenya have led to the progress and segmentation of the nation's gas and oil industry into three different sectors: upstream, midstream, and downstream. The upstream is still in its infancy, in contrast to the downstream and midstream parts, which have a rather mature economic and technological ecology. The exploration, drilling, and production sectors traditionally make up the upstream portion of the gas and oil industry. Geothermal drilling has been going on in Kenya despite the country's gas and oil business having fewer drilling and cementing activities than other major world oil and gas producing nations. Likewise, due to the early oil pilot project, Turkana oil has been online with some of it being stored at KPRL in Mombasa, and the rest at the tank farm in Turkana. This oil was transported using iso-heated road tankers since the Lokichar-Lamu oil pipeline is yet to be constructed.

2. Statutory Ecosystem

The gas and oil business is governed by a number of legislative and regulatory frameworks in Kenya. The Electric Power Act of 1997 was passed in the middle of the 1990s, while the Energy Act of 2006 was passed subsequently. The Energy Act of 2006 brought together all the laws pertaining to the energy industry and established the Energy Regulatory Commission (ERC – now EPRA) as the sole statutory regulator of the industry. This legislation provided the framework for the deregulation of petroleum product price, distribution, and sourcing. The Petroleum (Exploration and Production) Act of 1994 and the Petroleum Development Fund Act of 1991 had previously governed the petroleum industry. To further unbundle the energy sector, energy policies were outlined out in the Sessional Paper Number 4 of 2004.

2.1.1 Kenya Vision 2030

This is a new long-term development blueprint for the nation. The aim of Kenya Vision 2030 is to set up, a highly developed, affluent, and globally competitive nation by 2030. The flagship projects in Vision 2030 are listed with deadlines, the listed below is a summary of energy (oil and gas downstream sub-sector) specific projects to be undertaken by 2013:

- ✓ Boosted oil supply: Four booster pump stations were installed to increase the Nairobi-Mombasa oil pipeline's capacity from $440m^3$/hr to $880m^3$/hr, in Konza, Makindu, Manyani, and Samburu.
- ✓ Extension of the national Oil Pipeline from Nairobi to Eldoret using the same leeway as the old pipeline. It will be 340km.
- ✓ Joint Ventures: To extend the 352 km oil pipeline from Eldoret to Kampala, the government will collaborate with Tamoil East Africa Limited and the government of Uganda. This has not been achieved.
- ✓ Public-private partnership to build a 6,000-tonne Liquid Petroleum Gas (LPG) import handling facility in Mombasa.
- ✓ Nairobi will soon have a 2,000-tonne common user LPG handling facility built.

2.5 Policy Making Institutions in the Downstream Oil and Gas Sub-Sector

2.5.1 Ministry of Petroleum and Mining

The creation and coordination of overall policy for Kenya's oil and gas industry falls under the purview of the Ministry of Petroleum and Mining (formerly housed in the Ministry of Energy). Upon receiving guidance from the EPRA and the Energy Tribunal, it is in charge of creating policy. The Energy Tribunal, which was established by the Energy Act of 2006, is responsible for reviewing appeals from EPRA decisions.

2.5.3 Energy and Petroleum Regulatory Authority

The Energy Act No. 1 of 2019 and the Petroleum Act No. 2 of 2019 were signed into law on March 22. This effectively repealed the Energy Act No. 12 of 2006. Under the Energy Act of 2019, the Energy Regulatory Commission (ERC) was replaced by the Energy and Petroleum Regulatory Authority (EPRA), which has an expanded scope that includes, among other things,

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upstream coal and petroleum control. According to Section 10 of the Energy Act 2019, the Authority's duties (in the oil and gas downstream subsector) include

(a) Control the importation, reprocessing, exportation, sale, transit, storage, and other activities involving petroleum and petroleum products, excluding the sale of crude oil.

3 Oil and Gas Industry Infrastructure

For effective and efficient exploration, drilling, production, transport, refining, and distribution of gas and oil products, facilities are supposed to be in place. The advantages and disadvantages of operating oil and gas infrastructure are well known on a worldwide scale, [6]. Apart from the product pipeline from Mombasa to Nairobi, several gas and oil facilities are in operation in the country. The East African Community (EAC) and Great Lakes countries, like Ethiopia and South Sudan in the Northern Region and the Democratic Republic of the Congo in the Eastern Region, are supported by the gas and oil infrastructure in Kenya, which also guarantees the security of access and supply in the nations. The supply chain resilience and risk transfer techniques in Kenya's gas and oil industry are examined by [7]. Notably, managing supply chain risk is essential to the success of businesses in the gas and oil sector. The study finds that risk transfer influences supply chain resilience favorably and advises oil and gas companies to use risk transfer mitigation techniques to increase supply chain resilience. However, events of April 2022 in the Kenyan oil and gas landscape[1] testify otherwise as the conflict in Ukraine with Russia[2] sent crude oil prices skyrocketing.

The gas and oil supply chain in Kenya is supported by the following crucial facilities as discussed below:

3.1 Oil and Gas Exploration Equipment

Fossil fuel exploration entails the scientific and technological search for fossil fuels with the objective of exploiting them. This traditionally embodies the use of geophysical, remote sensing, and wildcats. Geophysical methods can be further divided into seismic surveys that use thumpers and geophones, three-dimensional (3-D), magnetometers, gravimeters, and geochemical prospecting[3] while remote sensing uses aerial photographs and side-looking airborne radar (SLAR), [8](Harbausg et.al 1977).

In the new facilities in South C suburb, Kawi House, Nairobi, NOCK has been putting up a processing center for seismology and an analysis laboratory for geochemistry and petrophysics. On the other hand, the country's geothermal reservoirs have been actively being investigated by the Kenya Electricity Generating Company (Kengen) and the Geothermal Development Company (GDC). They possess fully-fledged exploration departments with the accompanying equipment.

On the other hand, hydrogeological surveys have been ongoing in Kenya. The discovery of the Lokitipi aquifer in 2013, among other aquifers in Turkana county (the same county of Lokichar crude oil discovery in 2012), 300 meters below the surface, was done using an advanced hydrogeological survey[4]. The hydrogeologists were able to forecast profound structures that arise naturally using the Deep Aquifer Model (DAM), whose spatial distribution was represented by two-dimensional polygon shapes[5]. Analogously, oil and gas exploration and interpretation of the seismic results can be conducted at the NOCK laboratories. However, most international oil and gas firms have been using their own exploration equipment.

3.1 Oil and Gas Drilling Equipment

Fossil fuel reservoirs are tapped through the application of drilling processes. Historically drilling costs are directly related to the depth of the well. For instance, the cost variability of a geothermal well is linked to depth, [9]. Therefore, getting the right rig and its accessories plays a major part in ensuring that the overall cost of the operation is kept within the budget. Utilizing the fuzzy Delphi approach to assess the success of gas and oil drilling projects is one of the most recent trends, [10] as a tool for making robust economic and engineering decisions.

A drilling rig is one of the heaviest consumers of energy among the oil and gas upstream facilities. Efficient use of energy on a rig, therefore, calls for better energy management and storage [11]. With transient high load peaks, this makes it possible to more clearly determine the kind of storage that is most effective. The Kenyan drilling landscape is littered with several rigs, owned by Kenyan state firms namely Kengen and GDC, and also leased rigs mainly from China (Great Wall Drilling Company). Kengen owns and operates three drilling rigs, together with all the auxiliary equipment: two of them are electric land rigs with a capacity to drill up to 7km and one national drilling rig with a

[1] David Herbling, “Fuel Shortages in Kenya as Government Delays Subsidy Payment,” Bloomberg, April 4, 2022
[2] Samantha Gross, Dollar & Sense: The Brookings Trade Podcast, Washington D.C., Monday, April 4, 2022
[3] Exxon Corporation, 1982, The Upstream Magazine, December 1982, New York, NY, 29 PP
[4] Sean Avery, “The Turkana Aquifer Discoveries and Development Proposals”, November 2014
[5] Final Technical Report, “Advanced Survey of Groundwater Resources of Northern-Central Turkana County, Kenya”.

capacity to drill 2.2km, [12]. Additionally, the drilling operations of Kengen, go back to May 1956, with a total of over 300 wells drilled in Olkaria and Eburu geothermal fields. No wonder it has even attained the International Well Control Certification (IWCF). GDC on the other hand has seven deep-drilling rigs [13]. The latter are deployed mainly in the drilling of geothermal wells, but can still drill oil and gas wells. Interestingly, GDC and NOCK have an MOU (memorandum of understanding) for GDC to offer one of their deep-drilling rigs to NOCK for their oil drilling operations, [14]. The leasing of the rig to Zarara, a British oil and gas company wholly controlled by Midway Resources International (MRI), was made possible by the Great Wall Drilling company for the exploratory drilling of commercial gas for 120 days, in the Lamu Basin, Pate Island[6]. The approximate drilling bill was $159 million. The oil wells in Turkana were drilled by international contractors including Weatherford. Engomo-1, the first well drilled in North Turkana Basin, in block 10A, was drilled to a depth of 2,353 meters using the SMP-106, rig. SMP-5 was deployed for well completions in Amosing-1 and Amosing-2A, PR Marriot-46 rig drilled the Ngamia–7 appraisal well to a depth of 2,914meters, Weatherford 804 rig drilled the Ekales-2 appraisal well[7]. In 2018, Tullow Oil advertised the tender to drill 300 other wells[8]. According to their foundation phase schedule, the drilling of the 300 wells should have commenced in 2020 up to 2025. These wells are in Twiga fields, Amosing and Ngamia, while fields to the north of these current fields, will be set for production in the future. The objective, for now, is to produce at least 6 x10^4 – 8 x10^4 barrels of oil per day. Therefore, for these 300 wells to be drilled within the schedules, numerous drilling rigs will be required. Most of the pumps found on a drilling rig are used in pumping mud through the mud loop system. While some are duplex, others are triplex pumps that have to overcome frictional and hydraulic forces in order to push the mud thousands of feet to the nozzle bits and upward again to the surface. They are very basic pistons reciprocating inside a cylinder such that the reciprocation motion creates pressure and volume.

Figure 1. A drilling rig used for drilling the Lokichar crude oil in Turkana, Kenya (**Source**: Tony Karumba)

3.2 Oil and Gas Production Equipment

To prepare the produced oil for the market, it must pass through multi-phase separators. Oil and gas production equipment entails a network of systems for the separation of the well stream fluids into three different single-phase components – water, oil, and gas, and their subsequent transport and processing into finished products and or their disposal in an environmentally permissible manner. The Turkana oil is currently being produced from very few wells. Tullow Oil submitted its final development plan for the Turkana oil project in December 2021 [15]. Different production equipment will be set up for the production of the oil. A summary of the project overview is shown in figure 2 below.

Currently, Kenya does not have any offshore drilling and production platforms. Offshore oil platforms are huge

[6] Business Chief online magazine, 19th May, 2020
[7] Tullow Oil, "Kenya Exploration and Appraisal Update", Press Release, 11th March, 2015.
[8] Geoffrey Irungu, Business Daily, Wednesday June 27, 2018.

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engineering structures linked to the seafloor for facilitating exploration, production, storage, and processing of fossil fuels based in formations below the seabed. They may be singular structures or complex modules that comprise drilling, processing, residential, and power units. The array of topside facilities is impressive: pumps, valves, compressors, revolving cranes, control room, gas flaring stack, survival craft, docking units, risers, and a helipad. And in the well bay, we have fittings meters, Christmas trees, and sensors. On the drilling floor, we have drill bits, drill collars, stacks of drill pies, drilling consoles, fluid diverters, separators, kill and choke lines, and storage tanks for mud and water.

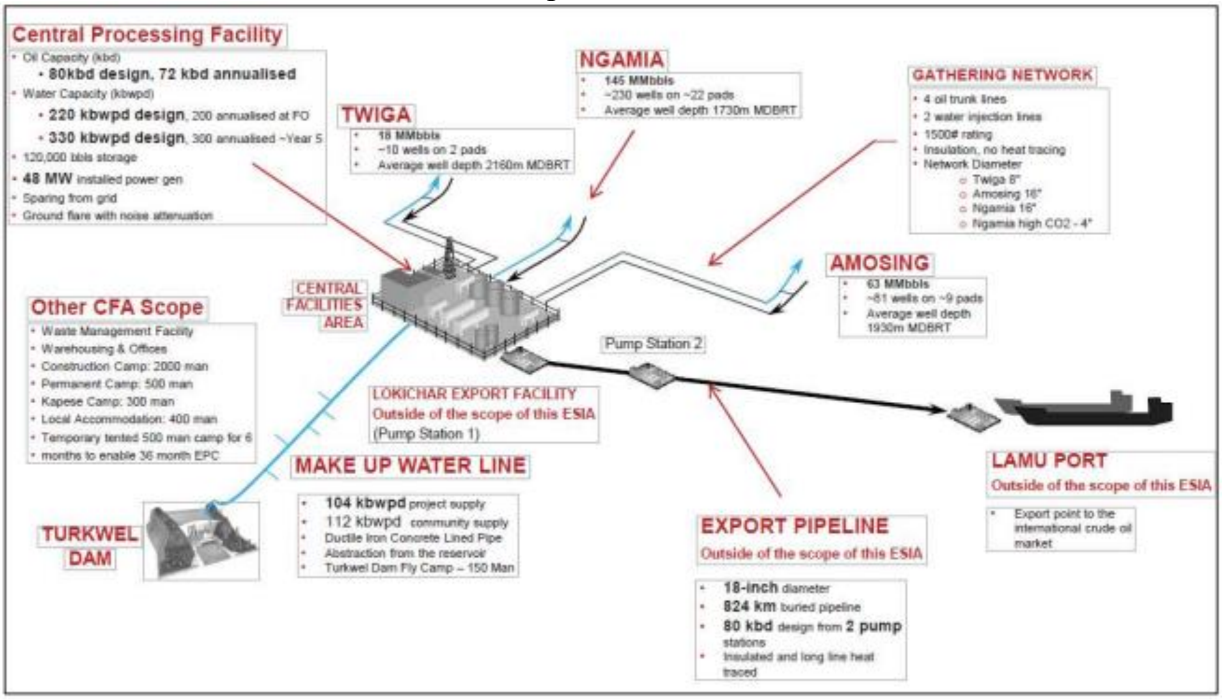

Figure 2. Turkana oil, the proposed full-field development facilities. (**Source**: Golder & Ecologic Consultants Ltd, 2020)

3.4. Oil and Gas Pipeline Network

Pipelines are the central node in the fossil fuels' network. They connect all other nodes essentially between the points of production and consumption. The two major types of pipelines are those that haul liquids and those that transport gas. Due to compositional differences, liquids and gas can't be transported in the same type of pipeline. Pipelines can further be categorized into gathering systems (these transport oil and gas from the wellhead to storage or processing facilities), transmission systems, and distribution systems. Gathering pipelines are short in length, operate under low pressure (≈700 psi), have small diameters (> 18"), and operate as interconnected networks that feed on multiple wells to processing facilities, and treatment plants of central gathering sites. Examples of these types of pipelines include flow lines that operate at approximately 250psi in smaller diameter size pipes (>12"), [16]. Transmission (trunk) lines are designated to haul crude oil and refined products (black and white products) across the country or intercontinental from producing zones to clients. They are longer than gathering lines, operate under higher pressure (200 – 1,200 psi), and have bigger pipe diameters (8" – 24"). Accompanying these pipelines usually are compressors, regulators, pressure gauges, valves, and pump stations along the pipeline route for flow and pressure maintenance, [16].

The last type of pipeline system is the distribution type. They entail mainlines and service lines applied by utility firms to deliver gas to clients. The pipes are small in diameter (>2") while mainlines are between 2" – 24" operating at less than 200psi. they connect the trunk lines and service lines [16].

The oil and gas pipeline in Kenya is mainly a transmission type. It is operated and owned by Kenya Pipeline Company. There isn't a single private oil or gas pipeline in the nation at the moment. The existing pipeline system is made up of trunk and distribution lines that span 1,804 km from Mombasa to Nairobi then onwards to Kenyan towns in the west, of Eldoret, Kisumu and Nakuru. This is shown in figure 3 below. Along these pipelines are several pumping stations and depots. The depots are located at Kipevu in Mombasa (PS14), Moi International Airport (PS12), Nairobi terminal (PS10), Embakasi (PS9), Eldoret (PS27), Nakuru (PS25), and Kisumu (PS28). Likewise, common user rail and road tanker loading facilities are situated in Nakuru, Kisumu, and Eldoret. Recently, a new twenty (20) inch pipeline (Line 5') measuring 450 km at a cost of $476.6 million from Mombasa to Nairobi was brought online to increase supply and enhance efficiency in oil and gas distribution in Kenya. Just like the refinery (KPRL) and the Kipevu oil terminal (50 years old), the first

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pipeline (Line 1) is aged (43 years old), a common denominator of gas and oil infrastructure in Kenya[9]. It had been designed to operate for 25 years and its replacement was due in 2003, but its life span was elongated for 14 more years, probably, one of the reasons it has had a leaky reputation, [17]. Transmission pipelines operate with mainline and booster pumps. Analogous to the heart in a human being, pumps drive the motion of the products inside the pipeline. For these pumps to operate, they need energy. While some operate on gas, others use electricity. For instance, the amount of electrical energy required for the pump to operate at its best is critical when evaluating the management of the pump's total costs and performance. A study evaluating the energy demand of the booster pump found that the energy demand of the mainline pump as a function of flow rate, density, and pump head determines the energy required of a booster pump, [18]. He further asserts that pump management remains crucial to the overall efficiency of the pipelines and shows that higher flow rates can be achieved in a pump without reaching the maximum allowable working pressure (MAWP) by using a looping system by deploying a drag-reducing agent (DRA) which reduces total dynamic pressure (TDP) and hydraulic friction losses.

Transnational transmission pipelines are usually beneficial to all stakeholders. However, they can also be a source of political conflicts [19], the most famous being the Nordstream 2 pipeline from Russia to Germany, which is a source of the current conflict in Ukraine (2022). This, therefore, brings into focus, the need for developing a new institutional mechanism devoid of geopolitical machinations and manipulations, but sensitive to every stakeholder, [20]. Unclear circumstances still revolve around how Kenya lost the right of hosting the East African Oil Pipeline that would have transported the Ugandan oil from lake Albert, through Lokichar and the Tamoil oil pipeline that would have extended from Eldoret to Kampala.

Storage

Facility	Storage (M litres)
Kipevu (Mombasa)*	326
Moi Airport (Mombasa)	7
KPRL (Changamwe)**	140
Nairobi Terminal	233
JKIA (Nairobi)	54
Nakuru	31
Eldoret	48
Kisumu	45
TOTAL	**884**

* Leased from MoPM
**Leases from KPRL

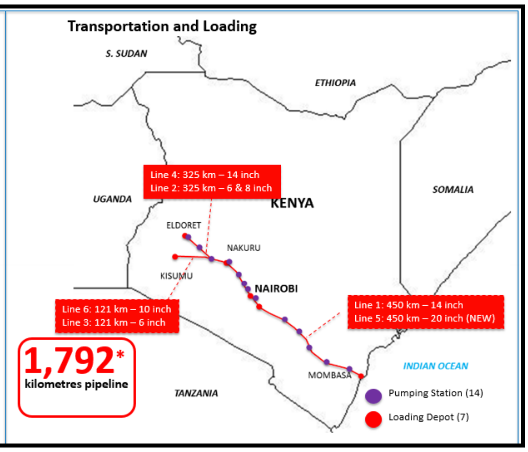

Figure 3. Current pipeline infrastructure in Kenya. **(Source:** KPC Website 2022**)**

3.5 Oil and Gas Import Terminals

An industrial facility known as a terminal is where products like oil, petroleum, and petrochemicals are stored before being transferred to customers and other storage facilities, [21]. Onshore terminals and floating marine terminals are the two categories into which terminals in the oil and gas sector are divided. These terminals' primary duties include receiving crude, processing it, storing it, shipping it, and metering it. The receiving equipment usually includes fixed roof receiving tanks, production meters, and scraper stations. Mechanical treatment includes three-phase separators and free water knockouts (FWKOs), skimmers, electrostatic desalters, etc. However, the terminals are not restricted to crude oil alone but also terminals for white refined products do operate. Currently, the largest number of oil terminals is in the USA [22]. However, nations like China and Nigeria are investing heavily in this type of infrastructure, [23].

Oil and gas terminals are expensive ventures. For instance, a new LNG terminal takes three to five years to build. The operations of the gas and oil terminals in Kenya are solely based on refined products importation. All these products are sourced from Asia, Europe, and the Middle East. Mombasa has served as the primary entry point ever since independence. A number of gas and oil terminals are in use for handling these imports while upholding safety and environmental regulations for the gas and oil sector. They are owned by both private players and government via Public-Private Partnerships (PPPs).

The main gas and oil terminals include:

a) *Shimanzi Oil Terminal* – This is a small terminal mainly used for the importation of oil products by small vessels. It can handle ships up to 259 meters in length and 35,000 DWT in weight. It can only hold 1,400 metric tonnes.

[9] The Kenyan Petroleum Industry 2019 - Research and Markets

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b) *Kipevu Oil Terminal* – This is used by large oil and gas vessels. Located at Kipevu along the Mombasa coast, it also includes a state-owned Kipevu Oil Storage Facility (KOSF). It handles vessels of up to 85,000 DWT and 198 meters long.

Figure 4. The new $385 million Kipevu oil terminal in Mombasa (**Source**: Robert Menza, 2021)

c) *AGOL* – A privately owned LPG dedicated facility, Africa Gas and Oil Limited was built under special conditions with Kenya Port Authority (KPA). It has numerous connections to regular users. It has six mounded LPG sphere tanks with a combined capacity of 14,500MT, along with associated pipelines, six rail tank carriers (RTC) loading bays, four truck loading racks, a 3.5 km, a firefighting water tank (2,500m^3), 14" delivery line from the SOT and from the proposed KOT2 common user manifold (CUM), a weigh bridge for trucks, a pump house and pipe network, and administrative, utility, and security buildings.

d) *Kisumu Oil Jetty* – Finished in 2018, it is an oil jetty located on Lake Victoria, which bounds three East African countries. It is utilized to export oil products to the countries bordering the lake. It is 95m long and can accommodate vessels of up to 90m in length and with a fuel carrying capacity of 3000 tones. It cost $30 million to refurbish and is set to facilitate the easy transportation of oil products to Rwanda, Eastern DRC, South Sudan, Burundi and Uganda. However, the jetty on the Ugandan side is still non-functional thereby delaying the full operationalization of the Kisumu oil jetty.

e) *Mbaraki Bulk Terminal* – This is a privately owned facility. It deals in palm oil, bitumen, diesel, heavy fuel oil, and kerosene. It is the only terminal that handles bulk bitumen. It has a storage capacity of 50,000 metric tonnes and can also handle huge ships weighing up to 50,000 DWT.

3.6. Oil and Gas Storage Tanks

The produced gas and oil, depending on the production gathering system in place, maybe temporarily stored. A tank farm, therefore, is an industrial facility made up of several huge cylindrical holding vessels. In most cases, they are constructed above the ground, together with auxiliary equipment like meters, valves, and pumps. They are made of steel and vary in size some having volumetric capacities of up to sixteen million gallons [24]. The construction of oil and gas storage tanks is special, unlike other civil engineering projects. The structures supporting tank farms used to store petroleum products need distinct and particular consideration. This is mainly due to the high load-bearing capacity of the products they will store for quite some time. This calls for special consideration of the soil during its construction [25], with lateral displacement, pore water pressure, and vertical settlement being the main parameters for evaluation.

The tank's behavior is assessed in relation to the shell, the connection between the shell and the bottom plate. Additionally, the distance between tanks is installed so that, in the event of a fire, nearby tanks are safe, [26]. This safe distance considers both windy and non-windy conditions, with Sholkri-Beyler's method for a windy velocity of less than 4m/s being considered optimal**.** The point source model determines the optimum safe inter-tank space when the wind speed is more than 4 m/s. However, in the case of fire emergencies, [27] opines that the firefighting emergency capability of a tank farm can best be evaluated using layers of protection analysis (LOPA) in identifying its weaknesses. Whereas globally, there are forty thousand nine hundred tank farms of every type in 161 countries[10] the number in Kenya is way below**.** Kenya has several tank farms, both for white and black products. Studies on their design are scarce and limited. Initially, tanks farms for white refined products were the only ones in operation, but with the onset of Turkana oil production, tank farms for crude oil have come online as well. Over 1,500,000,000 liters of white oil and gas products can be stored nationwide in their entirety. The Kenya Pipeline

[10] (http://www.tankterminals.com 2019),

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Company owns and runs more than 700,000,000 liters of this for primary and intermediate storage. Tullow Oil operates a tank farm for black oil in Turkana (figure 5 below), where crude is stored as it awaits hauling to the port of Mombasa.

Despite the engineering ingenuity involved in the construction of oil and gas tank farms, they still serve as sources of pollution. Sixteen prioritized polycyclic aromatic hydrocarbons (16-PAHs) were found in soils close to oil tank farms in Western Delta, Nigeria, [28]. The experts believe that the primary origins of these PAHs were low-high temperature combustion processes and petrogenic and suggested mitigation measures to curb their further effects on humans and the ecosystem around them.

Figure 5. Tank farm in Turkana for Lokichar oil. (**Source**: Tullow Oil, 2021)

3.7 Oil and Gas Refining Infrastructure

The produced crude oil and gas are usually destined for the refinery. There is no other oil and gas sub-sector where the complexity or Nelson Index of the infrastructure is more pronounced than in the refining sector. Refineries are traditionally costly, enormous, and monolithic engineering complexes where crude oil is transformed into different consumer products. The refining infrastructure in Kenya was mainly based at the Kenya Petroleum Refineries Limited (KPRL). It was established in 1960 by BP and Shell. Hydro-treating, distillation, catalytic reforming, and bitumen producing facilities were all put into operation in 1963. In 1971, the Kenyan government purchased 50% shares from Shell. In 1974, an additional refinery was launched at the same site, and in 1983, it was renamed Kenya Petroleum Refineries limited. Since its establishment, the Nelson Index of the KPRL refinery, which is necessary for profitable refining remained steadfastly low. Numerous challenges plagued the normal operations at the refinery. However, other small capacity refineries, faced with nearly similar challenges, made successful attempts to scale up production, diversify the production line and upgrade their technological processes.

Case studies in other African countries present a different scenario. For instance, the premier Nigerian Petroleum Refining Company initially had a simple hydro skimming plant with a capacity of 32,000 bpsd. Later it was modified to 45,000 bpsd, with an additional catalytic reforming unit added for producing naphtha with a high RON (research octane number) and high-value PMS. This capacity was again revamped to 60,000 bpsd. Additionally, following years of regular shortages of refined goods, the 635,000 bpd Dangote Refinery in Nigeria, will now be able not only to meet the domestic demand but also to export the surplus to neighboring countries, [29]. The Tema Oil Refinery in Ghana has a similar history, a simple hydro skimming unit with a capacity of 28,000 psd, which was later increased to 45,000 bpsd in 1997. In 2002, a Residue Fluid Catalytic Cracker (RFCC) was added to increase the yield of diesel and high-value PMS [30]. Just like in the above cases, KPRL is (was) a 32,000 bpsd facility. By September 2013, evidence of any major refurbishment or upgrading is grossly scarce. All along, KPRL strained to meet the needs of a growing market, forgetting to change technically as the times changed.

By the end of 2013, the refining equipment at KPRL could not meet the stringent environmental requirements of refined products the market was demanding. A series of feasibility studies, one by KBC Technologies of Britain in 2011 and a follow-up study by Engineers India Ltd (EIL) in 2012 didn't solve the problem, [31]. A costly investment of $17 million in a 9.2MW power plant from Wartsila Finland running on heavy fuel oil, only seemed to compound the chemistry at the refinery, when solar power would have been a significant option, [32]. Furthermore, a simple computer simulation using Hysys®Aspen software would have preliminarily pinpointed the optimum measures to undertake for its upgrading and modification, [33]. In the end, it became obsolete and is now a storage depot. Since a refinery is a relationship-specific asset (RSA), it means it cannot be reconfigured or repurposed for some other use without affecting its economic value. Therefore, the storage of Turkana crude oil at the refinery is only done in the holding tanks of the refinery and not in the atmospheric distillation column or any other reactor. KPRL has 45 tanks with a combined 484 million liters of storage space. 252 million liters

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are set aside for white products, while 233 million liters are set up for black products. The evaluation of the current state of non-operational assets like the diaphragm and positive displacement pumps, which are common in refineries for high-volume fluid transfer is vital to gauge the overall economic efficiency of transforming the former refinery into a storage depot. Having said so, one of the apparent reasons for the closure of the KPRL refinery was poor maintenance of equipment, [31] and so it became clear that revamping the refinery would be a costly venture, [26]. Conclusively, these columns are now historical technical monuments of a failed managerial reaction to change.

Figure 6. KPRL in Mombasa, Kenya (**Source**: KPRL, 2011)

3.8 Oil and Gas Retail Infrastructure

Refined gas and oil products are majorly destined for their client through retail gasoline stations. A typical oil and gas retail station entails fuel pumps, underground storage (fuel) tanks (UST) of a minimum capacity of 5m^3, metering devices, a service bay, wash bay, offices, wastewater drainage system, and firefighting equipment. As of 2018, Kenya had over 1,800 oil and gas retail stations, (Figure 7). With an overall population of 3,280,934 million vehicles (gasoline, diesel, light fuel units, 2018)[11], this represents a ratio of 1,823 vehicles per station. This implies the market of retail stations in Kenya is still under-saturated. As of January 2020, the cost of setting up a petrol station was approximately $1.9million. The annual cost of operating is $250,000 and $160,000 for purchasing and stocking the products. Despite the steep initial capital investment, petrol stations can be lucrative business ventures with the addition of such services as self-service and self-payment of fuel in addition to hosting fast-moving consumer goods outlets within their premises, [34]. Depending on the amount of land, the services provided, and the storage capacity, these stations are categorized as Tier 1, 2, 3, and 4. Other sources put the current retail network at 2,762 as at 2021.

Figure 7. A petroleum retail station in Kenya (**Source**: 2022)

The adaptation of IoT(internet of things) in retail stations is one more technology addition that is being posited among the oil and gas industry players. Proper telnet parameter tuning, auto-transmission of data, monitoring, and auto-upload, along with information management for gasoline stations, are some of the digital features that retail stations can implement in the quest to maximize the dwindling margins, [35] and economically withstand external market forces. On the other hand, retail stations and wholesalers have little market power to effect any significant impact when global oil shocks occur, [36] because in the long run they react symmetrically to an oil price spike. Thus, retail stations are left with the option of optimizing their operations through digitalization. In India, this trend seems to be taking root as the emphasis is on margins, [37] and as the basis of screening against insider pump price-setting inspections by regulators [38] due to

[11] WWW.CEICDATA.COM/KNBS

the widespread belief in fraud amongst fuel stations, [39]. In analyzing the challenges facing the key supply chain of oil and gas retail stations in Ghana, [40], the scholars recommended the Ghanaian government inject more capital into infrastructure and desist from interfering with its operations. A similar recommendation would be feasible for Kenya's oil and gas to retain the infrastructure setting.

3.9 Liquid Petroleum Gas (LPG) Infrastructure

In 2005, a study undertaken jointly by the World Bank and the Ministry of Energy concluded that LPG storage facilities with total capacities of 8700 tonnes be established in Nairobi, Mombasa, Kisumu, Eldoret, and Nakuru [41]. Evidence of the execution of these plans is rare.

On behalf of the Kenyan government, Toyota Tsusho Corporation was contracted in 2018 to conduct a feasibility study proposing the construction of an LPG import terminal in the Mombasa port. The terminal scale entailed pressurized tanks of 4,500 MT, while the 2nd phase comprised the refrigerated storage tank of 66,000 MT [42]. As of April 2022, the status of the project was unclear. In the same year 2018, Kenya Pipeline Company, through its chief executive officer, revealed grand plans of building a $65 million LPG handling and storage facility in Mombasa and a $60 million similar plant in Nairobi [43]. While the plant in Mombasa was set to handle 25,000 tonnes, the one in Nairobi would handle 10,000 tonnes of gas. Both facilities would have gas, rail, and truck loading and bottling facilities respectively. As of April 2022, all these noble plans remain grand pipe dreams.

In November 2011, NOCK installed and commissioned a mini-LPG plant in Nairobi, at its own premises in Industrial Area [44]. Flaunting it to be the first of its kind in the country, NOCK claims on its website, that the plant can even fill a 1 kg cylinder. And it has plans to replicate the same business model of mini-LPG plants around the country. LPG consumer cylinders in Kenya vary from 1kg, 2.7kg, 3kg, 6kg, 13kg, 16kg, 45kg and even 50kg. As of April 2022, the Nairobi plant was the only operational one while the rest remain in limbo. In February 2022, Kenya Pipeline Company announced plans to construct a bulk LPG storage facility on the 3-year leased premises of KPRL, [45]. This same plan had been mooted earlier on in 2016 but never materialized, [46]. The facility is expected to operate under the Open Tender Systems (OTS), where importers are permitted to trade with the lowest bids to import refined products on behalf of the industry. Apparently, it will also have rail siding, truck loading, and bottling facilities. The initial capacity will be 25,000 MT, with a further planned 50,000 MT in the long term. This facility will be linked to the second Kipevu Oil Terminal (KOT2). As of April 2022, this plan had not been executed.

The grand plans for oil and gas LPG infrastructure so visualized by the policymakers in Kenya would make grand impacts if only they would be executed.

3.10 New Oil and Gas Infrastructure Projects

a) *Mombasa LPG Import Terminal* - Africa Gas and Oil Ltd (AGOL) will construct the initial stage of a terminal for importing and storing LPG using a $23 million World Bank-IFC financing loan, a private firm that specializes in the importing, storage, and marketing of liquefied petroleum gas (LPG). This would enable a sustained rise in the uptake of clean energy sources in Kenya. The storage, related infrastructure, and direct mooring access for big LPG carriers will all have several loading sites for the transfer of LPG to rail and road transport. This infrastructure will enable the import of cooking gas in large quantities, lowering unit costs through economies of scale and reducing the frequency of shortages. The second phase will increase storage capacity to at least 25,000 metric tons, and the terminal will then be the biggest in sub-Saharan Africa with a 400,000 metric ton capacity for annual throughput. Kenya's ambitious plan for sustainable economic development will be supported by this project[12].

b) *Kipevu Oil Terminal* – KPA commissioned a new oil and gas terminal costing $385 million and by September 2020, it was 84% complete. According to KPA, the relocation of the Kipevi Oil Terminal to a new site was buoyed by the growth of the fossil fuel's industry in the country. The terminal that is now there, which is 50 years old, will be replaced by it. Four vessels with a combined deadweight tonnage of up to 200,000 will fit inside. The new oil terminal will feature three distinct kinds of white oil products (PMS-Petrol, DPK-aviation fuel and AGO-Diesel), four berths, and sub-sea (submerged) pipelines for five different petroleum products[13]. Expected to be the largest oil terminal in Africa, it is 770 m long with a capability of handling tankers of up to 200,000 deadweight tonnes [47].

c) *Tanga – Mombasa Gas Pipeline* – The long-term plan of interconnecting the energy infrastructure between Kenya and Tanzania was born when the leaders of Kenya and Tanzania signed an agreement for the study of the construction of a 600km gas pipeline from Tanga to Mombasa. The pipeline estimated to cost $1.1 billion will transport gas for use in cooking, heating, and power generation[14]. In the meantime, Kenya has hired K & M Advisors, a US-based entity, to carry out a feasibility analysis on the utilization of gas power generation in Mombasa [48]. In essence, this implies that in case Kenya finds a cheaper alternative then the agreement signed between the two neighbors becomes null. According to the Oxford

[12] John Mutua, Business Daily, 4th June, 2021

[13] KPA Website

[14] Iain Esau, Upstream Energy Explored, 12th May, 2021

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Institute for Energy Studies, more significant than its potential role as an oil and gas producer, is Kenya's significance as a continental center for gas and oil products in East Africa", [49]. This view is based on the estimated 750 million barrels of oil and gas reserves that Kenya now has, which are far less than what its neighbors have declared. It therefore will make more financial sense to share its oil and gas facilities with its neighbors. It must be from such understanding that the two leaders of Kenya and Tanzania signed the above agreement for a gas pipeline. Additionally, such collaboration will open opportunities for regional local content development.

d) *LAPSSET Corridor Development Authority* – A Presidential Order on Kenya Gazette Supplement No. 51, Legal Notice 58 of 2013, established the (LCDA). In charge of organizing, directing, and supervising the LAPSSET project's execution is the LCDA, which is located in the Presidency. According to LCDA, the regional project consists of nine different project elements. Budget estimates place the overall expenditure of the nine-infrastructure project integrants at $24.5 billion, according to the LCDA status report for 2016. Energy-related components of this mega project include:

i. Lamu Port: The building of a port with 32 deep-water berths in Lamu's Manda Bay. The port has been operationalized in accordance with the Marine Pollution Conventions and the International Maritime Organization's set of security guidelines for ships and ports (ISPS code). And in March 2021 with three operational berths (Berth 1, Berth 2, and Berth 3), normal trading ships began docking at it. Inline to be developed next are three berths.
ii. Crude Oil Pipeline: One of the project's main components, scheduled to stretch from South Sudan's Juba to Lamu through Isiolo, Nakodok, and Isiolo. However, the first emphasis will be from Lamu to Lokichar, this will cost an estimated $1.1 billion, with upstream activities costing an additional $2.9 billion. Australian Worley Parsons will design the pipeline.
iii. Product Oil Pipeline: The project will aim to reach oil reserves in South Sudan, Kenya, Ethiopia, Uganda and the Democratic Republic of the Congo (DRC), and running from Isiolo to Lamu, Moyale to Isiolo and to Addis Ababa to Moyale.
iv. Merchant Oil Refinery: The plan calls for building a refinery in Lamu and connecting it to Juba on both ends via a pipeline. Prior to shipping, it is intended to refine crude oil from both South Sudan and Kenya.

[50] evaluated variables influencing the execution of infrastructure projects with a focus on LAPSSET. Their studies concluded that public participation, environmental issues, need assessment, and project financing has a significant impact in enhancing the success of a project. While such a project may pose great development change for the country, the studies established that LAPSSET failed to engage the pastoralists in its planning activities thus sowing early seeds of potential conflicts in its execution.

This seems to be confirmed by [51] who has a sober opinion on the real input of LAPSSET in Kenya's Lamu county. He argues that the ground realities frequently challenge high-modernist and "new frontier" discourses. These situations offer as an illustration of complex economies of expectation, where alliance, mobilization and patronage, networks are being formed or strengthened prior to substantial investments. This is founded on widespread beliefs about ethnicity, land, and how these relate to politics of belonging and distribution. In particular, he argues that who will receive what, when, and how within its predicted prosperous future will be determined by these expectations rather than government designs.

3.10 Decommissioning

When gas and oil infrastructure is decommissioned, their wells are sealed and abandoned, and then the facility is reused or removed when it has served its purpose, [52]. The Petroleum Act of 2019, section 40 to section 44 outlines the decommissioning process of gas and oil infrastructure in Kenya. However, it seems to be geared more towards the upstream segment of the fossil fuel value chain than the entire gas and oil sector, leaving the midstream and downstream in a grey area. Globally, environmental concerns are now forcing different jurisdictions to embrace procedural decommissioning of their oil and gas infrastructures, [53]. Research is awash with decommissioning that is mostly orientated toward offshore facilities; however, onshore facilities do also reach the end of their lifecycles. For instance, after decades of crude oil production, the Brent Spar structure in the North Sea was intended to be disposed of in the sea, [54]. The intense policy issues it raised have served as a backbone of how oil and gas facility that has served their terms need to be "retired". Literature is now awash with different options on how to environmentally and economically decommission a facility [55]. Different methods can be used to define the assets that are ready for decommissioning, from life-cycle assessments (LCA) to material flow analyses (MFA) [56]. According to [57], at least seven different types of factors, including technical viability, cost, safety, the regulatory environment, environmental implications, political environment, and reputation, have an impact on how different stakeholders feel about decommissioning. However, most of the studies have been on offshore facilities with comprehensive detailed plans being addressed as shown in table 1.

Table 1. Issues Covered in This Decommissioning Assessment

No.	Assessed Quantitatively	Assessed Qualitatively
1	Material inputs	Clear seabed
2	Material endpoints	Personnel health and safety
3	Total energy requirements (TER)	Jobs at risk
4	Total gaseous emissions	Effects on sea and ocean ecology
5	Financial costs	Conservation of non-renewable resources
6		Influence on resource extraction
7		Effect on the fishing industry
		Impact on other marine life

For pipelines, the assessment is made based on the likelihood that they may be uncovered in the future, whether they are covered or trenched, and other factors. By employing sound risk mitigation methods and practices, pipelines can be repurposed to transport different fluids, [58]. For instance, views from KPC suggest that Kenya's oldest pipeline (Line 1) would be decommissioned after 43 years of service. According to the report, the 14" pipeline would be excavated and 279km of it disposed of as scrap metal while the 171km in Mombasa handed over to Mombasa Water Company for use in supplying water to the coast residents from Mzima Springs, [59]. However, other leaks indicate that the top KPC management was yet to decide on the way forward after suggestions of using it to transport natural gas from the coast or haul water were also floated, [17]. Apparently, a Dutch consultant is working on the way forward for this old pipeline. Likewise, once the huge Lokichar-Lamu crude oil pipeline is done hauling oil from Lokichar, it can reverse and start hauling desalinated water from Lamu to the thirsty Northern part of Kenya, [60], [61].

5 CHALLENGES

5.1 Turnaround Maintenance (TAM)

Due to the heavy capital outlay involved in the purchase of fossil fuels infrastructure, some gas and oil firms are considering operating these facilities beyond their originally designed field life and life generally. The normal lifespan of oil and gas facilities is 20-25 years. However, asset life extension (ALE) exposes the oil and gas infrastructure to exceptional commercial and safety risks, [62]. Some of these risks include: Wear, erosion, fatigue, slow-burn degradation mechanisms, cracking mechanisms, loss of technical competence; dynamic engineering standards and codes; equipment obsolescence; inadequate record-keeping of the precise status of critical elements (SCE) over time; and corroded building materials.

Proper maintenance of pipelines is among the difficulties plaguing fossil fuels infrastructure management. Pipelines for instance must deal with the hydraulic transient. These occur when there is a sudden or abrupt valve closure or pump failure as a result of a power outage. Such numerical methods and modeling can be deployed to assess the effects of hydraulic transients [63]. The strategy of a water supply company called for the operation of integrated equipment at each pump station and the installation of pressure relief valves and surge anticipator valves at each pump station. The valves discharge to a suction pipe on each pump station which in turn leads to a storage tank. Additionally, the tank serves as an air-break to isolate the main pipeline from pressure and transients while regulating peak pressures on the suction sides of the stations and acting as a shock absorber for transient waves. The ball pump control valves' stroking patterns, air vacuum valves, and anti-reverse ratcheting systems are also incorporated into the hydraulic transients' pump management system, [64]. In September 2020, KPC decided to work with the Samburu Area in Kwale county to perform spot repairs for an oil spillage that was caused by a "drastic pressure drop" on a pipeline section. As earlier indicated, most of the pipes deployed on the old pipeline were electric-resistance-welded (ERW) using carbon steel grade API 5L X52 standard. In general, as the asset ages, the challenge to maintain equipment and operational integrity increases. Therefore, life extension evaluations and analyses have to be undertaken founded on the use of these facilities beyond their designed lifespans. For any asset life extension program to succeed, the following are mandatory: data and information, gap assessment, risk factors, and maintenance management systems.

5.2 Safety, Health, and Environment

[65] Crawley (2004) opines that SHE policies should be integrated holistically from the onset of any oil and gas project, whether it is offshore or onshore. This is probably demonstrated in Qatar, where, the likes of the Occupational Health and Safety Administration (USA), Safety and Health Executive (UK), Chemical Safety Board, Control and Major Accident Hazards (COMAH), etc are absent, yet it has a very good safety record, [66].

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SHE policies in Kenya remain a grey area. From lackluster laws to inefficient implementation, the oil and gas infrastructure landscape is haphazardly aligned. This ailment appears to be pervasive in the execution of fresh gas and oil projects. Only three out of fourteen best practices criteria and techniques were adhered to by the projects in their evaluation of significant oil and gas projects, including Canadian gas and oil pipelines [67]. Evidently, the flaws included the absence of decision-making procedures containing legal obligations to compensate project opponents and guarantee that project benefits are distributed fairly, as well as the absence of a mechanism for comparing and contrasting competing projects.

5.3 Supplier Selection

The success of an oil and gas infrastructure depends wholly on the methods used in evaluating and determining the final supplier of the equipment. [68] found that the most crucial elements are price and quality employed in the selection of providers for gas and oil projects in the United Arab Emirates by utilizing analytic hierarchy process (AHP) and Delphi techniques. Furthermore, commercial and technological requirements are more important than company-specific requirements.

The Kenyan scenario is marked by cronyism and right connections than technical merit. Despite having been blacklisted in other nations[15], the Kenyan government went ahead and awarded the construction of a line5 pipeline to Zakhem international, a Lebanese construction entity. Midway through the construction, the price of the construction was changed upwards. After construction, the pipeline was leaking, and even puzzled the engineers, with the result of loss of refined products running into millions of dollars. Due diligence, sober accountability, and right responsibility were grossly missing in this case.

5.4 Expertise

In 2015, capacity for oil and gas technical skills. The fundamental objective is to develop an oil and gas technical training system and curriculum that is competency-based and meets the standards demanded by oil and gas firms.

Drilling is a crucial link in accessing oil and gas resources. The knowledge and skill of doing this are vital. GDC has a highly specialized simulator (apparently the only one of its kind in East and Central Africa) as a virtual rig, that has a complete and detailed immersive simulation experience of drilling. It mimics the 2000 horsepower rig with inbuilt pipe handling, mud systems operation, cementing operations, well control, tripping in, and even tripping out buttons on a large 3D imaging screen (ASM 2022). Even though it is geothermal-based, the gas and oil industry cadre can as well tutor on it. However, even with such equipment, the need for more digitally oriented training remains an obstacle. Specialized experts in new generation GIS (geographic information systems) [69] and other latest technological methods are rare to come by in Kenya

5.5 Economics

Due to the complex nature of gas and oil facilities, economic efficiency is only tenable when “smart fields” are considered. At the bottom of this approach is the net present value of the project. [4] opines that every development of any oil and gas infrastructure needs to incorporate flexibility, simplicity, and contingency. Additionally, he says that while deciding whether to move forward with development, the project's risky NPV is the most crucial factor. This view is confirmed by combining development and production planning in one model, then rough estimates of costs and revenues can be calculated [70]. Even more detailed and performance capability of predicting the net present value is when systems engineering is incorporated into the assessment of gas and oil projects [71]. However, [72] suggests a completely new approach of alternative contracting strategies where the owner (so long as he is competent enough) is increasingly involved and the engineering and construction contractor acts as the owners’ agent and not the adversary. They concur, however, that this will necessitate organizational and behavioral changes from facility owners as well as contractors. In his study,[5] seems to align with the position put forth by Berends. He recommends using critical price, comprehensive barrel cost, and internal rate of return as additional economic indicators in the integrated planning process for offshore gas and oil exploration and production.

5.6 Security

Oil and gas infrastructure, with its highly flammable, toxic, and energetic content, has always been an attractive target of disgruntled employees, criminals, and terrorists [73]. [74], who show that third-party interruption is the most important safety element among the important risk variables of gas and oil pipeline undertakings examined in Iraq, support this viewpoint. Likewise, [75] shows the importance of security for gas and oil infrastructure in Yemen as one of the risk factors that have to be integrated into the planning. However, these security concerns are not limited to the physical disruptions alone. Due to the automation and digitalization of these infrastructures, the potential of hacking and cyber-attacks is real. In 2020, the Colonial company that operates fossil fuel pipelines on the east coast of the USA was hacked using ransomware. The responsible hackers

[15] John Kamau, “Lebanese firm Zakhem on the spot over Sh48billion pipeline”. Nation.Africa, Wednesday, June 28, 2020

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demanded a ransom, which was paid in cryptocurrency of 75 Bitcoin, which is approximately $5 million, [76].

A recent attack on the construction crew of LAPSSET in Lamu by the Al-Shabab highlights the very present risk of terrorism on oil and gas infrastructure in Kenya, [77]. Additionally, these disputes over oil and gas have spread beyond Kenya's internal borders and into the international sphere, as seen by Kenya's withdrawal from a crucial ICJ hearing regarding the conflict over its maritime border with Somalia, [78]. The conflict is centered on a triangle-shaped marine region where oil and gas reserves are allegedly located. Therefore, any oil and gas offshore installation in this region will automatically become a security issue.

5.7 Environment

Oil and gas facilities tend to impact the environment wherever they are set up [79]. [80] recommended regional strategic environmental impact studies and the use of roadless extraction techniques after examining these projects in the Western Amazon. In their study on the evaluation of the significance of environmental elements in the development of gas and oil facilities, [81] further underlines this. Their finding is that when building oil and gas plants, environmental protection should be carefully considered.

A draft National Oil Spill Response Contingency Plan and a draft Dispersant Use Policy are also available for the country. However, the research found that if a significant spill occurred, these drills and training sessions would not be sufficient to handle it, and there are still gaps in the legislation regarding oil spill planning and response. The current major causes of waste generation from the downstream oil and gas sub-sector include:

a) Petroleum retail outlets
b) KPC depots
c) Port of Mombasa
d) KPRL
e) Industries that

To prevent future local conflict, Kenya should take into consideration both national and local socio-ecological factors, although the conditions for inclusive growth have not yet been created. In an effort to stop climate change, it may be necessary to phase out gas and oil resources, this might lead to abandoned assets in both developed and developing countries. This will result in developing countries being poorer because abandoned assets are more expensive than abandoned resources.

5.8 Legislation

One of the risks widely studied for oil and gas infrastructure remains bureaucratic government systems in the developing world, [82]. Kenya is among the developing nations in pursuit of developed nation status. For instance, one of the unique features of the establishment of fossil fuel infrastructures in Kenya is the acquisition of land from private holders to the government, then to the gas and oil firms. In the process, these private citizens must be compensated. Intriguingly, compensation for the Kenyan landowner takes approximately two years. And this was one of the reasons put forth by the Ugandan delegation as Kenya attempted to convince its landlocked neighbor to evacuate its crude oil from Lake Albert through Kenya [83]. The valuation is solely the work of the National Land Commission. Whereas they are scenarios where only a small section of private land is taken, some other cases involve entire parcels of land. The issue of valuation thus becomes controversial. For instance, in Canada, the sale price of rural residential properties with 4 km or less from an oil and gas facility is dramatically impacted, [84].

6 Recommendations

The infrastructure for gas and oil in Kenya has been examined in this essay. It has shown how one area of the economy has the potential to either improve a country's living standards to incredibly high levels or drive an entire community into levels of poverty that are unfathomable to humankind. Therefore, it impartially suggests the following actions as essential:

a) The digitalization of gas and oil facilities in Kenya is the way to go. Wear and tear can be made known through sensor-based robotic automation, machine learning, artificial intelligence, and data analytics before they occur, failure modes and failure patterns for equipment types, highlight the performance features of specific manufacturers or types of equipment and code them. And this information can be stored securely in the cloud drives, [85,86,87].

b) The need for research and development in advanced drilling technology is paramount for improving the drilling system, [88] with the main focus being research into smart drilling systems at a national level. This would benefit both oil and gas drilling and geothermal drilling.

c) All stakeholders should undertake appropriate environmental adherence, oversight, and mitigation measures with the advent of climate change to benefit society and avoid the risk of stranded assets.

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d) Effective public education campaigns on citizens' rights and their realistic demands of the fossil fuels industry should be included, supported, and empowered in the country's laws.

e) Constant benchmarking, internal auditing and self-reflection forums, and workshops on the returns from the extractive industry should be held both at the national and county levels. The same zeal and passion witnessed in marketing Kenyan tourism around the globe should be reproduced internally in the gas and oil industry.

f) Physical security measures geared toward securing the gas and oil infrastructure can include the installation of closed-circuit television (CCTV) surveillance at strategic places, restriction of unauthorized third-party access in oil and gas equipment areas, perimeter protection, and proper lighting [89].

7 Conclusion

The goal of this study was to evaluate the most recent studies conducted by various scholars and make an effort to compare and contrast their findings in relation to Kenya's oil and gas industry. It follows that if Kenya wants to make efficient and effective use of its expensive oil and gas infrastructure, it must be adaptable and flexible enough to react to the technical dynamics, environmental requirements, and economic changes occurring throughout the world. Only then, will the energy investments in Kenya have both the desired net present value but also net social value.

Declarations

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Authors' Contributions

Antony Fundia Simbiri: Conceptualization, Methodology, Simulation, Modeling, Sensitivity Analysis, Writing-Original draft preparation, reviewing and editing. Joel F. Ogbonna, Emmanuel E. Okoro, Daniel O. Oyoo: Supervision:

Conflict of Interest

The authors declare that they have no competing interests.

Data Availability

The authors declare that the data supporting the findings of this study are available within the paper. Should any raw data files be needed in another format they are available from the corresponding author upon reasonable request. Source data are provided with this paper.

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Abbreviations

COFEK – Consumer Federation of Kenya,

EIA – Energy Information Administration

EPRA – Energy and Petroleum Regulatory Authority

FWKO – Free Water Knockouts

KPA – Kenya Port Authority

KNBS – Kenya National Bureau of Standards.

LAPSSET – Lamu-Port-South Sudan-Ethiopia Transport

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