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Review Article

Advances in Domestic Natural Gas Utilization in the Power Sector in Nigeria

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Abstract

Nigeria's vast natural gas reserves hold immense potential for addressing the country's power generation challenges and enhancing energy security. This review paper examines advancements in natural gas utilization for power generation in Nigeria, focusing on power plant development, gas infrastructure expansion, and technological innovations based on existing literature on related topics. The study explores the growing adoption of gas-fired power plants, expanding gas processing and transportation infrastructure, and integrating modern technologies to improve efficiency and sustainability. Despite these advances, several challenges persist, including infrastructure deficits, policy and regulatory bottlenecks, financial constraints, and environmental concerns. Limited gas transportation and storage facilities, frequent pipeline vandalism, and weak policy enforcement hinder the full realization of Nigeria's gas-to-power potential. Additionally, the financial burden of infrastructure investments and the negative environmental impact of gas flaring pose significant obstacles to sustainable development. To overcome these challenges, this paper highlights key policy and strategic recommendations for strengthening gas infrastructure, improving regulatory frameworks, attracting investment, and promoting environmental sustainability. Expanding the gas pipeline network, enhancing Liquified Natural Gas (LNG) storage capacity, and implementing advanced gas processing technologies are critical to ensuring a reliable gas supply. Furthermore, enforcing stringent environmental policies, fostering public-private partnerships, and incentivizing gas-based power projects can drive long-term energy security and economic growth. While significant progress has been made in natural gas utilization for power generation, addressing existing barriers through strategic investments and policy reforms is essential. By leveraging its abundant gas resources, Nigeria can achieve a sustainable, efficient, and resilient power sector, fostering industrial development and national economic transformation.

Keywords

Natural Gas, Gas Utilization, Power Generation, Gas Reserve, Economic Growth, Energy Security

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1. Introduction

As the global community increasingly shifts attention toward transitional energy sources to reduce greenhouse gas emissions and combat climate change, natural gas is gaining attention worldwide, primarily due to its relatively cleaner-burning properties and widespread availability [1]. Around 22% of the total global power generation in 2017 was estimated to be sourced from natural gas, making it the most utilized fuel in the power sector after coal [2, 3]. This global momentum toward gas as a transitional fuel presents both challenges and opportunities for Nigeria: while it underscores the urgency for technological advancement and infrastructure development to meet growing global and domestic gas demand [1], it also opens avenues for Nigeria to shift from a predominantly export-driven gas economy to one that drives domestic power generation, industrialization, and economic diversification. By leveraging this shift, Nigeria can unlock a significant multiplier effect, stimulating job creation, attracting investment, and enhancing energy security. It can overcome infrastructure gaps, weak policy frameworks, and environmental concerns.

Endowed with one of the world's largest proven natural gas reserves, Nigeria has significant potential to leverage this resource for economic development, particularly in the power sector [4]. Despite this vast natural gas wealth, the country continues to experience chronic electricity shortages, hindering industrial growth, economic productivity, and overall socio-economic development. The inefficient utilization of natural gas, coupled with infrastructural deficiencies and policy gaps, has constrained efforts to expand power generation capacity and ensure energy security [5-7]. Addressing these challenges is essential for Nigeria to transition toward a more stable and sustainable energy system, reduce reliance on costly and environmentally harmful alternatives, and support industrialization and economic growth.

The paper reviews the advances in domestic natural gas utilization in the power sector in Nigeria to assess the current state of natural gas utilization for power generation in Nigeria, explore the recent advancements in gas-fired power generation, highlighting the key challenges hindering effective gas utilization for power generation while providing policy and strategic recommendations for sustainable gas-to-power development and importantly, outlining the role of natural gas in Nigeria's energy security and economic growth.

This article explores key areas shaping Nigeria's power sector development. Section 2 provides an overview of Nigeria's natural gas resources, discussing the country's resource potential and the policy landscape that governs natural gas exploration, production, and utilization. It further establishes the foundational understanding of Nigeria's natural gas industry and the regulatory framework shaping its role in power generation.

Section 3 delves into recent advancements in natural gas utilization for power generation, focusing on power plant developments, gas infrastructure improvements, and technological innovations that have enhanced the efficiency and capacity of natural gas-fired electricity generation based on related existing literature. These developments are crucial for addressing Nigeria's persistent electricity supply challenges and maximizing the benefits of its abundant gas reserves.

Section 4 outlines the challenges hindering natural gas utilization in Nigeria's power sector. These include infrastructure deficits, policy and regulatory issues, financial constraints, and environmental concerns. Understanding these barriers is critical to formulating effective strategies to enhance gas utilization and drive sustainable energy development.

Section 5 presents policy and strategic recommendations aimed at overcoming these challenges. It discusses strengthening infrastructure, enhancing policy implementation, promoting financial incentives, and addressing environmental issues to foster a more efficient and sustainable natural gas-powered electricity sector.

Finally, the paper concludes the discussion by summarizing key insights and reinforcing the importance of advancing domestic natural gas utilization to support Nigeria's power sector, economic growth, and environmental sustainability.

2. Natural Gas in Nigeria: An Overview

Nigeria has one of the world's largest natural gas reserves, estimated at over 209 trillion cubic feet (TCF) as of 2023 [8]. Despite this vast resource, domestic gas utilization, particularly in the power sector, has historically faced challenges such as inadequate infrastructure, regulatory bottlenecks, and pricing issues [9]. However, recent advancements indicate a growing shift towards optimizing natural gas for electricity generation.

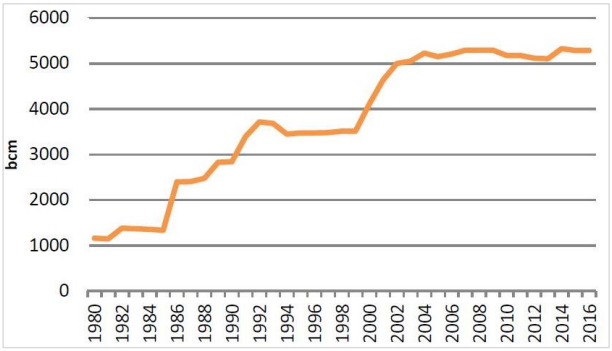
One key development in this sector is the expansion of gas-fired power plants. The Nigerian government's National Gas Expansion Programme (NGEP) aims to increase domestic gas consumption, focusing on power generation [10]. Additionally, the construction of new gas processing facilities and pipelines, such as the Ajaokuta-Kaduna-Kano (AKK) pipeline, is expected to enhance gas supply to power plants [11].

Furthermore, policy reforms, including the 2008 Nigerian Gas Master Plan and the 2021 Petroleum Industry Act (PIA), have provided a framework for improved gas commercialization and utilization [12]. These initiatives are expected to reduce gas flaring while ensuring a steady feedstock supply to power stations. Integrating gas-to-power projects, including embedded generation and mini-grid solutions, expands electricity access in underserved areas [8].

While significant progress has been made, challenges remain, including inadequate investment, regulatory hurdles, and gas supply disruptions. Addressing these issues will be critical to fully harnessing Nigeria's natural gas potential for sustainable power generation.

2.1. Resource Potential

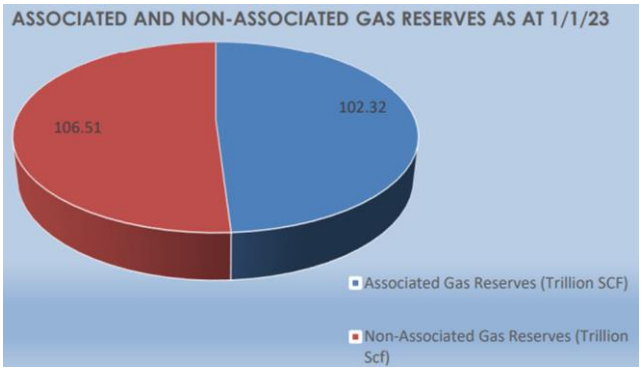
Natural gas plays a critical role in Nigeria's energy strategy, with a strong focus on domestic utilization for power generation and as a cleaner alternative to petroleum-based fuels [13]. The government has intensified efforts to expand gas infrastructure, enhance processing capabilities, and support industrial adoption to optimize its economic and environmental benefits.



Source: BP Statistical Review of World Energy 2017 [15]

Figure 1. *Natural Gas Proven Reserves in Nigeria, 1980-2016.*

Nigeria boasts the largest proven natural gas reserves in sub-Saharan Africa, primarily located in the Niger Delta Basin, which holds over 80% of the reserves [14]. However, the country has historically underutilized its gas potential, with a significant portion lost to flaring, reinjection, and inefficient distribution networks. To address this, the government has pursued a Gas Master Plan to accelerate domestic gas consumption and ensure a sustainable supply chain. Figure 1 shows the growth of natural gas proven reserves in Nigeria from slightly over 1000bcm in 1980 to over 5000bcm in 2002 [15]. Figure 2 indicates that Nigeria's gas reserves status as of January 1, 2023, is 208.83 TCF [16].



Source: NUPRC (2023) [16]

Figure 2. *Nigeria's Associated and Non-Associated Gas Reserves as of 1/1/23.*

S/NO	COMPANIES	CONTRACT TYPE	TERRAIN	GAS PRODUCTION			GAS UTILIZATION	GAS FLARED	GAS SHRINKAGE	% GAS FLARED
				AG	NAG	AG+NAG				
1	SHELL	JV	Onshore/Offshore	67,241.50	281,397.61	348,639.11	332,682.45	15,956.66	-	5
2	SNEPCO	PSC	Deep Offshore	34,099.63	-	34,099.63	33,450.23	649.40	-	2
3	CHEVRON	JV	Offshore	134,087.24	123,755.08	257,842.32	243,278.97	14,563.35	-	6
4	CHEVRON STAR DEEP	PSC	Deep Offshore	153,521.54	-	153,521.54	150,240.74	3,280.79	-	2
5	MOBIL	JV	Onshore/Offshore	305,096.59	-	305,096.59	282,133.45	22,963.14	-	8
6	ESSO	PSC	Deep Offshore	150,749.44	-	150,749.44	141,540.23	9,209.22	-	6
7	NAOC	JV	Onshore/Offshore	97,858.44	92,916.61	190,775.04	176,418.06	10,654.90	3,702.08	6
8	TEPNG	JV	Onshore/Offshore	181,297.08	103,770.20	285,067.27	278,497.22	4,899.49	1,670.56	2
9	TUPNI	PSC	Deep Offshore	187,178.66	-	187,178.66	184,179.81	3,056.88	-	2
10	NAE	PSC	Deep Offshore	10,454.37	-	10,454.37	6,486.46	3,967.91	-	38
11	ANTAN PRODUCING	PSC	Onshore/Offshore	21,641.38	-	21,641.38	6,595.43	15,045.95	-	70
12	PAN OCEAN	PSC	Onshore	10,072.50	-	10,072.50	9,013.89	1,058.61	-	11
13	NEPL	SR	Onshore/Offshore	96,688.66	152,345.09	249,033.74	217,029.57	32,004.17	-	13
14	ENAGEED	PSC	Onshore	931.58	-	931.58	87.97	843.60	-	91
15	AMNI	SR	Offshore	2,350.77	-	2,350.77	1,759.70	591.07	-	25
16	MONIPULO	MF	Offshore	192.41	-	192.41	16.41	176.00	-	91
17	ARADEL	MF	Onshore	3,573.22	6,117.54	9,690.76	9,623.98	66.78	-	1
18	CONTINENTAL	SR	Offshore	2,446.67	-	2,446.67	233.17	2,213.51	-	90
19	CONSOLIDATED	SR	Offshore	197.13	-	197.13	77.36	119.77	-	61
20	DUBRI	SR	Onshore	667.51	-	667.51	8.14	659.37	-	99
21	PLATFORM	MF	Onshore	3,454.25	6,990.44	10,444.68	9,961.29	483.40	-	5
22	WALTER SMITH	MF	Onshore	448.77	3.67	452.44	297.82	154.62	-	34
23	MID WESTERN	MF	Onshore	799.36	-	799.36	60.63	738.73	-	92
24	PILLAR	MF	Onshore	647.44	-	647.44	381.66	265.77	-	41
25	GENERAL HYDROCARB	MF	Offshore	1,502.27	-	1,502.27	-	1,502.27	-	100
26	ENERGIA	MF	Onshore	-	6,896.50	6,896.50	4,333.88	2,562.61	-	37
27	Britania-U	MF	Offshore	97.57	-	97.57	74.05	23.52	-	24
28	SEPLAT	JV	Onshore	17,059.66	84,640.78	101,700.45	93,803.24	7,897.21	-	8
29	ORIENTAL ENERGY	MF	Deep Offshore	5,252.86	-	5,252.86	4,128.18	1,124.68	-	21
30	SEEPCO	PSC	Onshore	8,924.55	42,705.95	51,630.49	51,623.91	6.58	-	0
31	FRONTIER	MF	Onshore	226.85	46,900.51	47,127.36	46,856.62	270.74	-	1
32	New Cross E&P	JV	Onshore	6,486.10	-	6,486.10	3,436.73	3,049.37	-	47
33	EROTON (NOEL)	PSC	Onshore	-	5,666.93	5,666.93	5,608.67	58.26	-	1
34	UNIVERSAL ENERGY	MF	Onshore	544.03	-	544.03	40.45	503.58	-	93
35	AITEO	JV	Onshore	4,292.99	-	4,292.99	1,729.38	2,563.61	-	60
36	NETWORK	MF	Onshore	924.30	-	924.30	35.34	888.96	-	96
37	BELEMA OIL	JV	Onshore	115.88	-	115.88	64.15	51.74	-	45
38	YINKA FOLAWIYO	SR	Deep Offshore	-	-	-	-	-	-	#DIV/0!
39	GREEN ENERGY	MF	Onshore	1,988.86	-	1,988.86	-	1,988.86	-	100
40	EXCEL	MF	Onshore	183.32	-	183.32	101.17	82.15	-	45
41	MILLENIUM	MF	Onshore	481.78	-	481.78	-	481.78	-	100
42	SGORL	PSC	Onshore	149.84	-	149.84	147.38	2.45	-	2
43	CHORUS ENERGY	MF	Onshore	-	3,968.10	3,968.10	666.08	3,302.02	-	83
44	FIRST E& P COMPANY	MF	Deep Offshore	9,182.36	-	9,182.36	618.48	8,563.88	-	93
45	ALL GRACE ENERGY	MF	Onshore	207.66	-	207.66	-	207.66	-	100
46	HEIRS HOLDING OIL &	JV	Onshore	7,034.29	7,056.37	14,007.57	11,244.64	2,762.93	-	20
47	NEWCROSS PETROLEUM	PSC	Onshore	7,479.23	-	7,479.23	7,479.23	-	-	-
				1,537,830.5	965,131.4	2,502,878.8	2,316,046.3	181,517.9	5,372.6	7.3

Source: NUPRC 2023 [16]

Figure 3. *Gas Production, Utilization & Flared Gas in Nigeria, January 2023.*

Infrastructure remains a key driver of Nigeria's gas agenda. As of 2007, 124 gas infrastructure projects were at various stages of implementation [17], ranging from exploration and production to transportation and storage facilities. The Nigerian Gas Master Plan (2008) prioritized quick wins through gas commercialization, contributing to an estimated $14 billion in economic value [18]. The plan also examined the feasibility of gaseous fuels as a medium-term substitute in transportation, a move aimed at reducing dependency on imported fuels.

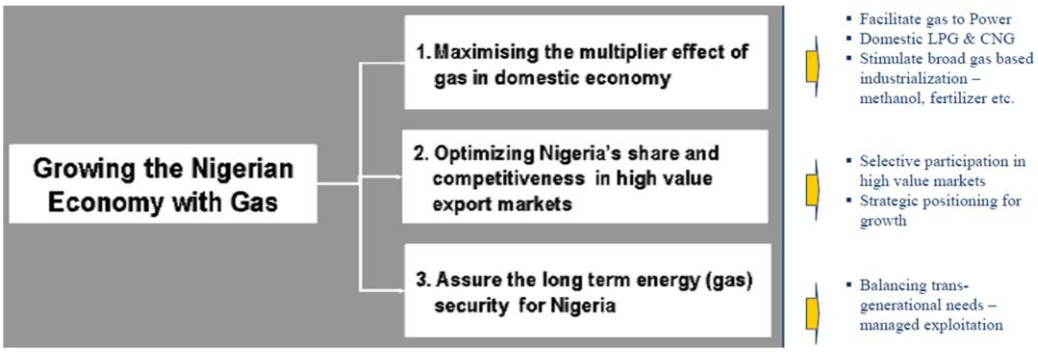
Despite these initiatives, the sector still faces challenges. Approximately 25% of Nigeria's natural gas (3 billion cubic feet per day) is still flared [18, 19], resulting in economic and environmental losses. Figure 3 shows Nigeria's gas production, utilization, and flared gas chart by oil and gas companies, with the annual flared gas being 7.3% of production as of January 2023 [16]. Of the gas infrastructure projects outlined in the government's master plan, only five are under construction. Furthermore, gas pricing remains a key determinant of industry growth, with rising demand necessitating a balanced approach to domestic pricing policies and supply chain improvements [18].

In the short term, gas infrastructure expansion is expected to increase supply availability and reduce flaring by 40-45% compared to 2006. In the medium to long term, fluctuations in global energy markets, infrastructure investments, and regulatory frameworks will shape the trajectory of domestic gas utilization. As demand for natural gas surges across industries, it is crucial to update pricing models and assess economic impacts to ensure affordability and sustained sector growth [20, 21].

2.2. Policy Landscape

The policy framework governing natural gas utilization in Nigeria's power sector has evolved significantly, reflecting global energy trends, climate commitments, and economic diversification efforts. Given Nigeria's vast proven natural gas reserves, leveraging gas for power generation has become a national priority [22-24]. However, in Nigeria, regulatory bottlenecks, infrastructure deficits, and pricing challenges continue to hinder the full potential of natural gas in the power sector [25].

Historically, over 60% of Nigeria's natural gas has been flared, as much of it is associated with oil extraction [20, 26]. Gas flaring not only results in significant economic losses but also contributes to severe environmental degradation, especially in the Niger Delta region. Pollutants from flaring cause soil acidification, deforestation, and damage to aquatic ecosystems, exacerbating socio-environmental challenges [20, 27]. Nigeria's government has introduced several policies to mitigate these effects, including the Nigeria Gas Flare Commercialization Program (NGFCP) and the Gas Master Plan, which aim to reduce flaring and incentivize gas monetization for power generation [20, 28]. Figure 4 outlines the objectives of the NGMP [29].



Sources: NNPC 2007 [29]

Figure 4. *Objectives of the Nigerian Gas Master Plan.*

The National Gas Policy (2017) was a significant step toward creating a competitive gas market, promoting gas-based industrialization, and reducing flaring [30]. The policy called for price liberalization, fiscal incentives, and expanded infrastructure, yet challenges such as a lack of enforcement, inconsistent pricing mechanisms, and funding constraints have slowed its impact. Similarly, the Nigeria Gas Flare Commercialization Program (NGFCP) was introduced to reduce gas flaring and repurpose flared gas for electricity generation. Still, its implementation has faced delays due to legal and investment hurdles [26, 28].

The Nigerian Decade of Gas Initiative (2021-2030) further emphasizes domestic gas utilization to address Nigeria's persistent power shortages, aiming to transition the country to a gas-powered economy [28, 31]. However, gas supply constraints, outdated infrastructure, and bureaucratic inefficiencies impede progress [32]. The Nigerian Presidential Power Initiative (PPI) and the Electricity Act (2023) have also aimed to enhance private sector participation, streamline regulations, and boost investments in the gas-to-power value chain [33].

While policies like the NGMP and the Nigerian Gas Transportation Network Code (NGTNC) were designed to create a more structured gas market, implementation challenges persist due to inadequate financing, policy inconsistencies, and weak enforcement mechanisms [31]. Furthermore, the fluctuating global gas market and concerns about energy transition have raised questions about the long-term viability of gas investments in Nigeria [33, 34].

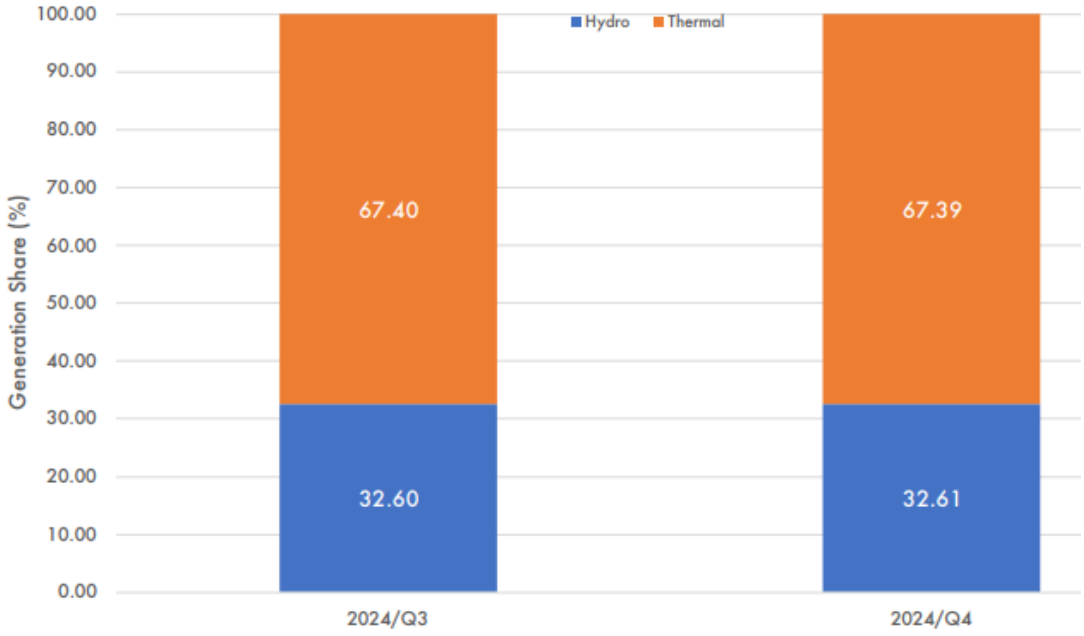
Nigeria must address policy gaps, ensure regulatory stability, and attract long-term investments to maximize natural gas utilization in the power sector. Strengthening public-private partnerships (PPPs), improving pricing frameworks, and incentivizing domestic gas production will achieve energy security, economic diversification, and environmental sustainability in the coming years [35].

3. Advances in Natural Gas Utilization for Power Generation

Nigeria, with one of the largest proven natural gas reserves in Africa, has made significant strides in harnessing this resource for power generation [24]. As the country grapples with chronic electricity shortages and the need for cleaner energy solutions, natural gas has emerged as a pivotal component of its energy strategy. This section explores the latest advances in natural gas utilization for power generation in Nigeria, focusing on power plant development, gas infrastructure expansion, and technological innovations shaping the sector.

3.1. Power Plant Developments

Nigeria's vast natural gas reserves present a significant opportunity to enhance power generation through gas-fired plants. Over the years, the country has prioritized expanding and developing gas-powered plants to address its persistent electricity deficit and transition toward cleaner energy sources [36]. The chart of Figure 5 shows that natural gas accounts for about an average 67.4% of electricity generation in Nigeria in 2024/Q3 and 2024/Q4. The subsequent subsection explores the progress made in power plant development, including new projects, capacity expansion, challenges, and policy-driven initiatives shaping the sector.

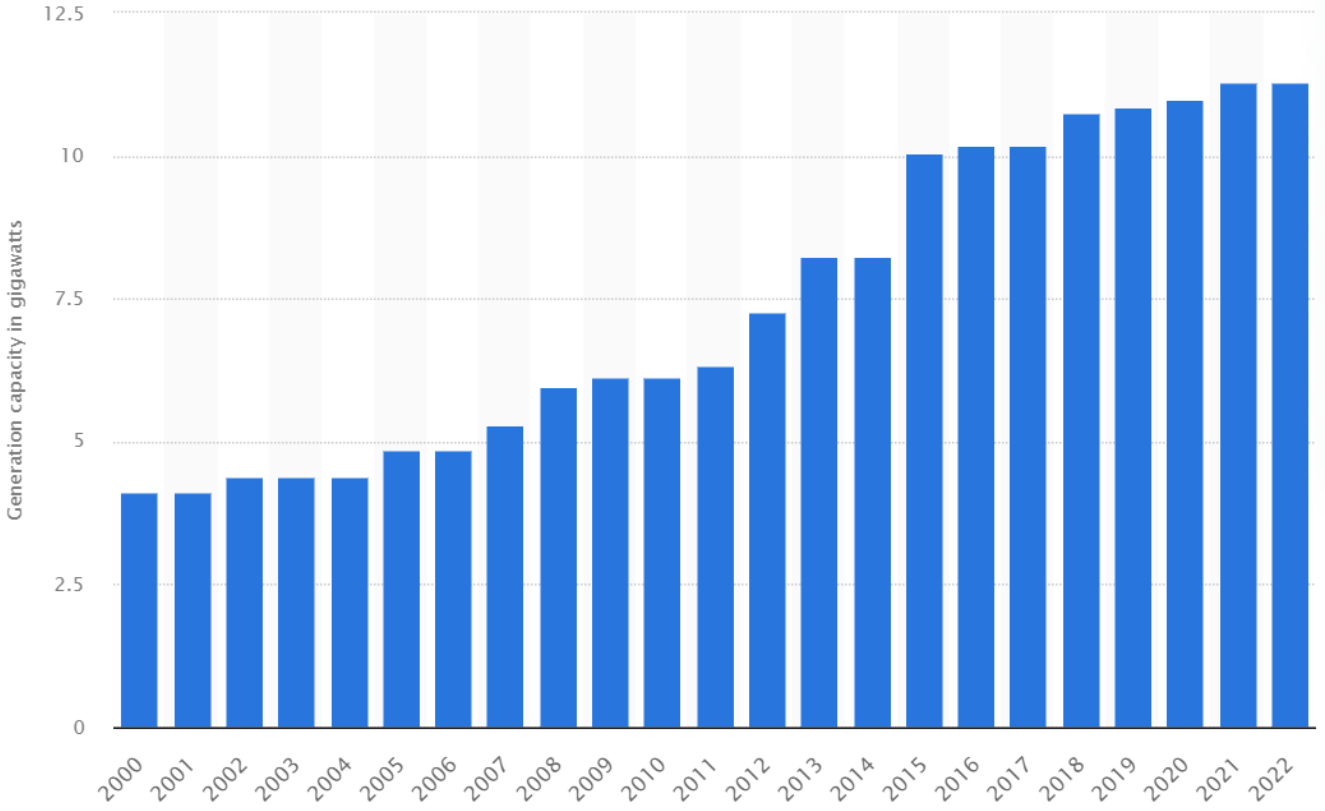


Source: [37]

Figure 5. *Nigeria's Electricity Generated by Energy Sources (%) in 2024/Q3 vs. 2024/Q4.*

3.1.1. Expansion of Gas-fired Power Plants

The Nigerian power sector has seen an increase in natural gas-fired power plants, contributing to the country's energy mix. Major plants such as Egbin, Geregu, Omotosho, Olorunsogo, and Afam VI have supplied electricity to the national grid [38]. Recent developments include the construction of the Azura-Edo Independent Power Plant (IPP), a 461 MW facility, and the expansion of the Geregu Power Plant, which added 434 MW of generation capacity [5]. The Ajaokuta-Kaduna-Kano (AKK) pipeline project is also expected to boost gas availability for new power plants in northern Nigeria, thereby increasing the country's overall generation capacity [28, 39]. According to Figure 6, there was a gradual increase in Nigeria's generation capacity from barely 4.11 gigawatts in the year 2000 to a peak generation of [40].



Source: [40]

Figure 6. *Installed Generation Capacity of Gas in Nigeria from 2000 to 2022.*

3.1.2. Public-private Partnerships and Investment in Gas-to-power Projects

The Nigerian government, through initiatives like the Power Sector Recovery Program (PSRP) and the Gas Master Plan, has encouraged private-sector participation in power generation [41]. Independent Power Producers (IPPs) now play a vital role in Nigeria's electricity market, with projects such as the 540 MW Qua Iboe Power Plant and the 1,320 MW Okpai Phase II plant developed under public-private partnerships [22, 42]. Foreign direct investments from companies like Siemens and General Electric have further accelerated power plant development by introducing advanced gas turbine technology to improve efficiency [43].

3.1.3. Challenges in Power Plant Development

Despite notable progress, several challenges hinder Nigeria's efficient operation and expansion of gas-fired power plants. A significant issue is inconsistent gas supply due to inadequate infrastructure, frequent pipeline vandalism, and regulatory constraints [42, 44]. Additionally, Nigeria's aging infrastructure and technical inefficiencies reduce the operational capacity of existing plants. Many power stations, including Afam and Olorunsogo, operate below installed capacity due to maintenance issues and gas shortages [25, 42, 45]. Figure 7 shows Average Available Capacity (MW) in 2024/Q3 vs. 2024/Q4 of some of Nigeria's power plants, with Egbin_1 having the most available capacity of 528MW in 2024/Q3 and 615MW in 2024/Q4.

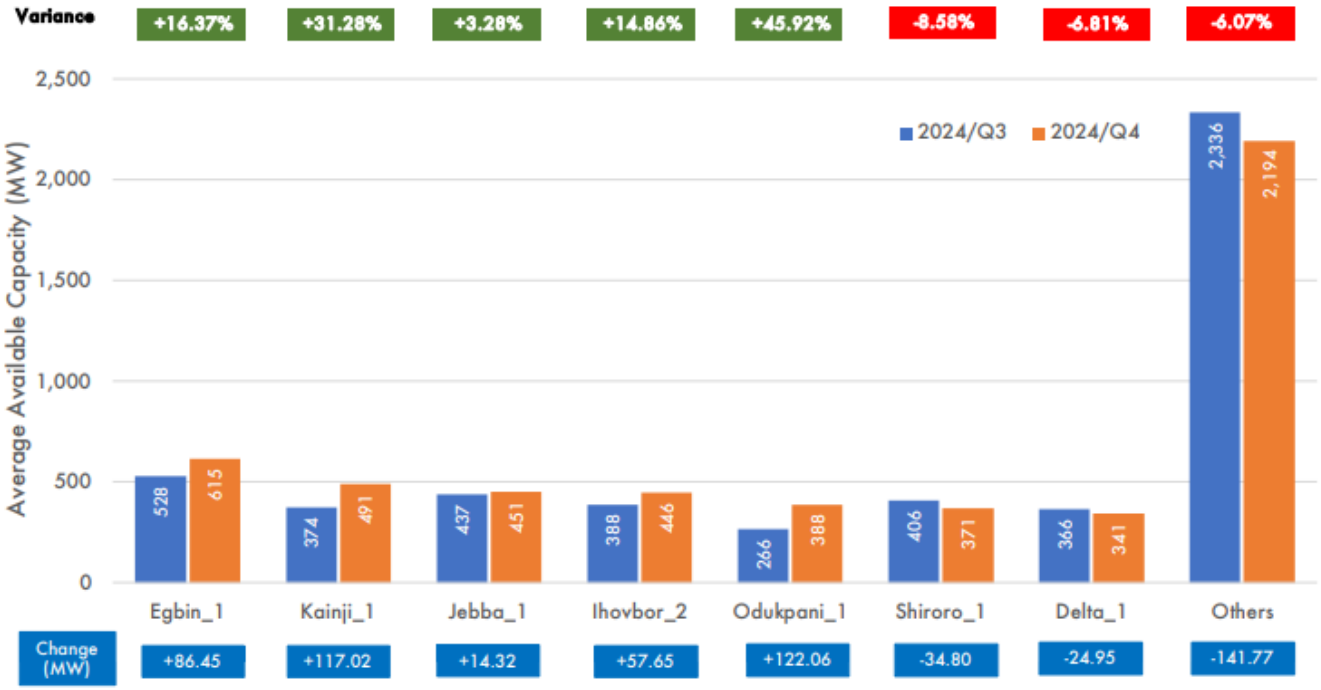
3.1.4. Government Initiatives and Policy Reforms

The Nigerian government has implemented various policy measures to mitigate these challenges and improve power plant efficiency. The National Gas Expansion Programme (NGEP) seeks to enhance gas availability for power generation. At the same time, the Electricity Act 2023 aims to decentralize electricity governance, allowing states to generate and distribute power independently [6]. The introduction of cost-reflective tariffs and regulatory incentives has also encouraged private-sector investment in gas-to-power projects.

3.1.5. Future Outlook for Gas-powered Generation

The future of gas-to-power development in Nigeria depends on sustained infrastructure investment, regulatory improvements, and innovative technologies such as combined-cycle gas turbines (CCGT) and floating LNG power plants [46]. With an increasing focus on reducing gas flaring and optimizing domestic gas utilization, Nigeria is poised to achieve greater energy security by expanding gas-fired power plants.

Power plant development is critical to Nigeria's natural gas utilization strategy. While significant progress has been made in expanding generation capacity through new projects and policy initiatives, persistent challenges must be addressed to achieve a stable and efficient gas-to-power sector. Continued investment in infrastructure, policy reforms, and technology adoption will be essential in unlocking the full potential of Nigeria's natural gas resources for sustainable electricity generation.



Sources: [37]

Figure 7. *Average Available Capacity (MW) in 2024/Q3 vs. 2024/Q4.*

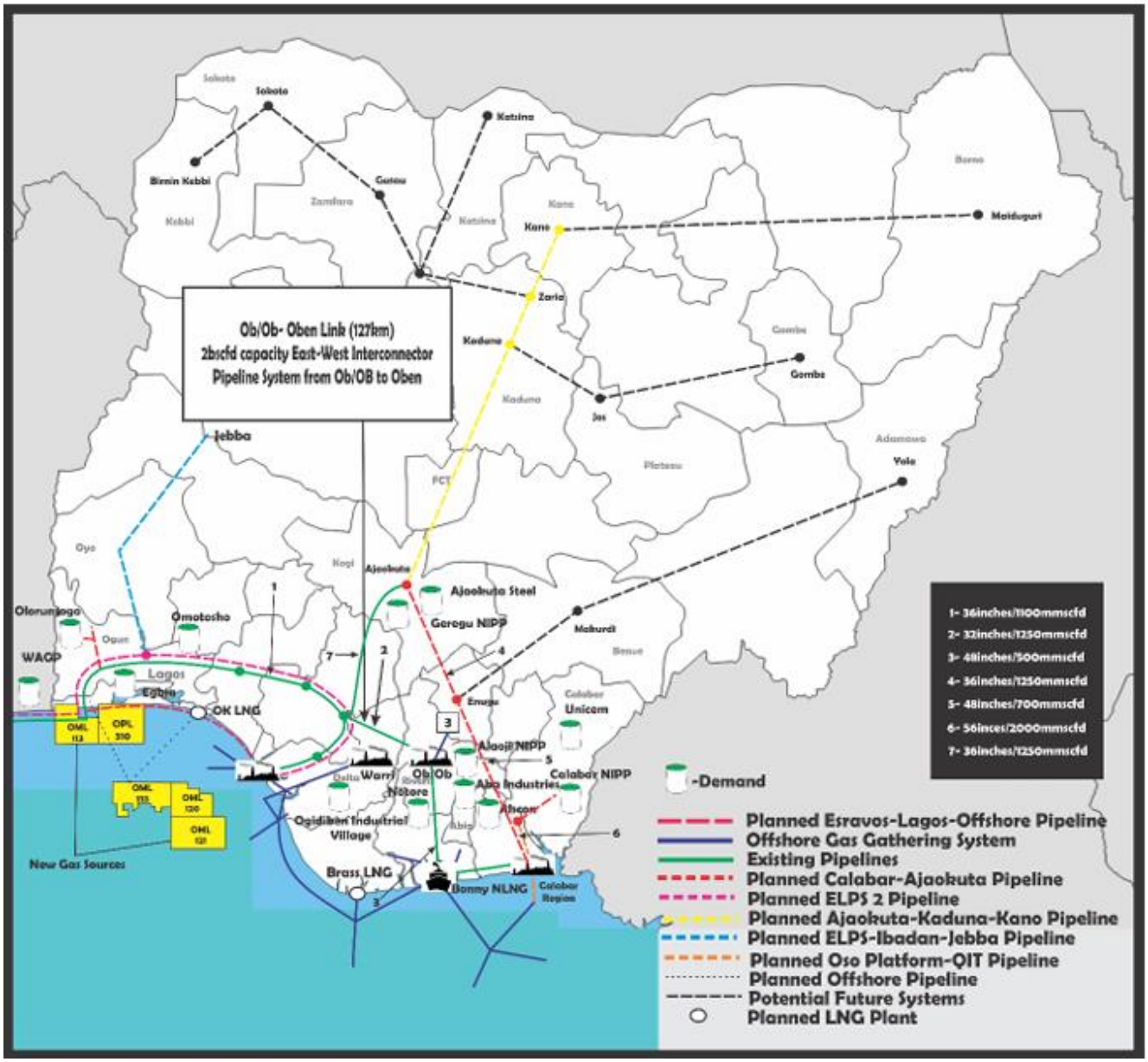
3.2. Gas Infrastructure

The development of gas infrastructure is crucial for enhancing natural gas utilization in Nigeria's power sector. Adequate infrastructure ensures the efficient transportation, processing, and distribution of natural gas to power plants, reducing dependence on less efficient and more polluting energy sources [47]. This section explores key developments in gas infrastructure, including pipeline networks, gas processing facilities, storage systems, and emerging investments in gas transportation.

3.2.1. Expansion of Gas Pipeline Networks

Gas pipeline infrastructure is fundamental in delivering natural gas from production fields to power plants and other end-users. Nigeria has an extensive but aging gas pipeline network that has experienced significant expansions in recent years to improve supply reliability [48]. The Escravos-Lagos Pipeline System (ELPS) is one of the most critical gas transmission routes, supplying natural gas to power plants in Lagos and Ogun states. Similarly, the Oben-Geregu pipeline facilitates gas delivery to the Geregu Power Plant in Kogi State [49].

One of the most ambitious projects in Nigeria's gas infrastructure expansion is the AKK Gas Pipeline, which is expected to boost power generation in northern Nigeria by transporting gas from the southern producing regions [49]. The Nigerian AKK pipeline, currently under development, is part of the government's broader strategy to create a nationwide gas grid and reduce energy disparities between regions [50, 51]. The map in Figure 8 shows that existing infrastructures are concentrated in Nigeria's southwest and northcentral (Ajaokuta) zones, which have massive potential for economic productivity.



Source: [16]

Figure 8. *Map showing Gas Demand and Infrastructure Blueprint.*

3.2.2. Gas Processing and Compression Facilities

Nigeria has made notable progress in developing gas processing facilities to remove impurities and enhance the quality of gas supplied to power plants [52, 53]. Key processing plants include:

1. Escravos Gas Processing Plant (EGPP): Operated by Chevron Nigeria Limited, this facility supplies processed gas to the ELPS for power generation.
2. Oben Gas Plant: Managed by Seplat Energy, this facility contributes significantly to the domestic gas supply.
3. Utorogu and Ughelli Gas Plants: These plants, located in the Niger Delta, are vital in ensuring stable gas supplies to power plants in the western gas network.

Gas compression stations like Oben and Itoki have been upgraded to improve gas flow efficiency and reduce pressure drops that could affect transmission reliability [49, 54].

3.2.3. Storage and Liquefied Natural Gas (LNG) Development

Gas storage infrastructure remains underdeveloped in Nigeria, limiting the ability to ensure uninterrupted supply to power plants, especially during production disruptions [5, 55]. However, efforts are underway to enhance Nigeria's gas storage capacity. For instance, the Central Gas Processing Facility (CGPF) project aims to introduce large-scale underground storage solutions [56 -58].

Liquefied Natural Gas (LNG) has also emerged as a viable

option for addressing gas distribution challenges, particularly off-grid power solutions. The NLNG Train 7 expansion project is expected to increase LNG output and create opportunities for small-scale LNG adoption in decentralized power generation [57, 59-60]. According to [61], the project kick-off for five mini-liquefied natural gas (LNG) facilities in Ajaokuta, Kogi state, was carried out in January 2025. These facilities are meant to ensure efficient gas transportation over long distances, providing a cleaner and cheaper energy source to households, mobility, industries, and businesses. Floating LNG (FLNG) terminals are also being explored to improve gas supply reliability [62]. According to [63], Nigeria's UTM Offshore is executing its Floating Liquefied Natural Gas (FLNG) project, with the front-end engineering design completed in October 2023. The facility, which will process 2.8 million tonnes per annum, will consist of 2.1 MTPA LNG, 500kT/yr LPG, and 200kT/yr condensate, with a final investment decision expected in Q1 2025. [64] Reports that Wison New Energies is commencing design and pre-FEED work on two FLNG production projects in Nigeria, with a combined capacity of 6 MTPA. The projects are owned by Nigerian companies Ace Gas, FLNG, and Transoceanic Gas & Power.

3.2.4. Future Outlook and Strategic Investments

The Nigerian government has introduced several policy measures to address these challenges, including the Decade of Gas Initiative, which seeks to improve gas infrastructure across the value chain [65]. The recent passage of the Petroleum Industry Act (PIA) 2021 is also expected to create an enabling environment for increased private sector investment in gas infrastructure [52].

Furthermore, the expansion of gas-to-power industrial clusters is being promoted to optimize infrastructure utilization and reduce transmission losses. These developments will be essential in unlocking Nigeria's full potential in natural gas utilization for power generation.

Gas infrastructure is a critical component of Nigeria's power sector transformation. While significant strides have been made in expanding pipelines, processing facilities, and LNG projects, challenges such as vandalism, regulatory uncertainties, and funding constraints persist. Future investments and policy reforms will be instrumental in ensuring a stable and efficient gas supply for power generation, ultimately enhancing Nigeria's energy security and economic growth.

3.3. Technological Innovations

Technological advancements have played a crucial role in improving the efficiency, reliability, and environmental sustainability of natural gas utilization in Nigeria's power sector. Innovations in power plant efficiency, gas processing, and emerging technologies are critical in addressing Nigeria's energy challenges and optimizing natural gas resources for electricity generation [66, 67]. This section explores key technological developments, including advanced gas turbine systems, combined-cycle power plants, gas-to-power innovations, and digital monitoring solutions.

3.3.1. Advanced Gas Turbine Technology

Advanced gas turbine technology has transformed power generation globally by enhancing thermal efficiency and reducing carbon emissions [68, 69]. In Nigeria, adopting modern gas turbines such as high-efficiency aero-derivative and heavy-duty industrial turbines has improved the reliability and output of gas-fired power plants. However, integrating this technology within Nigeria's unique environment presents notable advantages and challenges.

Advantages:

1. Improved Thermal Efficiency and Fuel Utilization: Advanced turbines such as the Siemens V94.2 STG5.2000E installed at the Geregu Power Plant in Kogi State have significantly improved fuel-to-power conversion efficiency. This is particularly beneficial in Nigeria, where natural gas is abundant but often underutilized or flared due to infrastructure bottlenecks.
2. Enhanced Operational Stability: The deployment of Siemens SGT-800 turbines at the Egbin Power Plant has demonstrated improved grid stability and reduced downtime, which is critical in a country plagued by frequent power outages and unstable electricity supply [70].
3. Fuel Flexibility: These turbines can operate on a range of gaseous and liquid fuels, offering resilience in the face of Nigeria's inconsistent gas supply due to pipeline vandalism and aging infrastructure.
4. Support for the Decade of Gas Initiative: Advanced gas turbine systems align with Nigeria's Decade of Gas Initiative, promoting cleaner, more efficient energy production as the country transitions from diesel and coal toward natural gas.

Disadvantages and Challenges:

1. High Capital and Maintenance Costs: While operational costs may be lower over time, the initial capital outlay for advanced gas turbines is substantial. Many Nigerian power plants face funding limitations, and access to long-term financing remains challenging.
2. Technical Skill Gaps: The operation and maintenance of advanced turbine systems require specialized skills in short supply locally. This results in dependence on foreign experts, increasing costs, and limiting rapid fault resolution.
3. Environmental Conditions: High ambient temperatures and dusty conditions in parts of Nigeria can reduce turbine efficiency and increase maintenance frequency. These environmental factors can lead to premature component degradation without adequate filtration and cooling systems.
4. Infrastructure Constraints: The effectiveness of advanced turbines depends on a reliable gas supply and

grid infrastructure. However, Nigeria's gas delivery network is often disrupted, and the national grid is weak and frequently overloaded, which limits the full utilization of high-capacity turbines.

3.3.2. Combined-cycle Power Plants (CCPPs)

The transition from simple-cycle to combined-cycle power plants (CCPPs) represents a significant advancement in Nigeria's power generation strategy. CCPPs integrate gas and steam turbines to harness waste heat for additional electricity generation, thereby improving thermal efficiency and lowering greenhouse gas emissions [71, 72]. This approach is particularly relevant for Nigeria, given its vast natural gas reserves and growing demand for cleaner and more reliable energy.

Advantages:

1. Enhanced Efficiency and Output: CCPPs can achieve efficiency levels above 60%, compared to approximately 35% for simple-cycle plants. Facilities such as the Azura-Edo Power Plant (450 MW) and Okpai Power Plant (480 MW) have demonstrated how CCPPs maximize energy production from limited fuel inputs, which is critical in a country where energy demand far outstrips supply.
2. Reduced Fuel Consumption and Emissions: By utilizing waste heat, CCPPs reduce overall fuel usage, aligning with Nigeria's environmental goals and Decade of Gas initiative. Plants like Afam VI benefit from lower fuel costs and reduced emissions, supporting national efforts to cut down on gas flaring and environmental degradation.
3. Support for Grid Stability: The steady and higher output from CCPPs stabilizes Nigeria's fragile national grid, helping reduce blackouts and frequency fluctuations in areas connected to facilities like Azura-Edo and Okpai.
4. Utilization of Domestic Gas Resources: Nigeria holds one of Africa's largest proven natural gas reserves [4]. CCPPs provide a practical means of converting this resource into dependable electricity while mitigating gas flaring in oil-producing regions.

Disadvantages and Challenges:

1. High Capital Costs and Project Delays: The construction of CCPPs requires significant investment, sophisticated engineering, and long development timelines. In Nigeria, bureaucratic red tape, land acquisition issues, and difficulties securing financing compound these challenges.
2. Infrastructure Limitations: The effectiveness of CCPPs depends heavily on a stable gas supply and a reliable transmission network, both of which remain underdeveloped in Nigeria. Gas pipeline vandalism, leakages, and grid constraints frequently hinder full utilization of installed CCPP capacity.
3. Water Requirements for Steam Cycle: CCPPs require substantial water for steam generation and cooling, which poses a challenge in Nigeria, where water access is limited or seasonal. This environmental factor may impact long-term plant sustainability.
4. Technical and Human Capacity Gaps: Operation and maintenance of CCPPs require highly skilled engineers and technicians. Nigeria faces a shortage of such specialized personnel, often necessitating the involvement of foreign contractors, which raises operational costs and slows local capacity development.
5. Environmental Conditions and Equipment Wear: High ambient temperatures, dust, and humidity in many parts of Nigeria can reduce the operational efficiency of turbines and accelerate wear on components, necessitating frequent maintenance and air filtration upgrades.

3.3.3. Gas-to-power Innovations

Recent innovations in gas-to-power (GTP) technologies are playing a significant role in addressing Nigeria's persistent electricity deficit and improving the utilization of its abundant natural gas reserves. One of the key advancements is the development of compact modular gas power plants, which can be deployed quickly in remote and underserved areas. These plants are particularly well-suited to Nigeria's geography, where many rural communities remain disconnected from the national grid. Their scalability and relatively short construction timelines offer a practical solution to bridging electricity access gaps [68].

However, the deployment of these modular systems also faces challenges. Nigeria's poor road and logistics infrastructure can hinder the transport and installation of equipment, especially during the rainy season when roads in rural areas often become impassable. Additionally, limited local technical capacity for maintenance and operation can lead to reliability issues and dependence on foreign expertise.

Small-scale liquefied natural gas (LNG)-to-power solutions have also emerged as a viable strategy for off-grid and industrial power generation. These systems involve transporting LNG by road to power generation sites, bypassing the need for expensive and often vandalized pipeline infrastructure. This model is advantageous in a country with common pipeline sabotage and gas supply disruptions. Moreover, LNG-to-power solutions offer greater flexibility and can be implemented faster than traditional pipeline-connected plants.

Nonetheless, this approach has drawbacks. The lack of cold-chain logistics infrastructure and poor road safety can complicate LNG transportation. At the same time, the high upfront costs of cryogenic storage and regasification facilities can be a barrier for small-scale operators.

A more recent innovation gaining momentum in Nigeria is Floating LNG (FLNG) technology. Projects like the UTM Offshore FLNG are designed to process gas in offshore fields and deliver it directly to onshore power facilities or export markets. This approach can significantly enhance gas supply reliability, reduce flaring, and make offshore gas resources more commercially viable [73].

Despite its promise, FLNG technology faces steep capital

and technical barriers. Nigeria's maritime and engineering sectors may lack the specialized skills and infrastructure required for efficient deployment and operation. Furthermore, environmental risks, including potential gas leaks or marine ecosystem disruptions, necessitate stringent regulatory oversight, which remains underdeveloped in the Nigerian context.

Gas-to-power innovations offer significant potential to transform Nigeria's energy landscape. While the technologies are technically sound and increasingly adaptable, their success in Nigeria depends on addressing infrastructure limitations, building local capacity, and implementing robust regulatory frameworks to ensure safe, sustainable, and reliable power generation.

3.3.4. Digital Monitoring and Smart Grid Integration

Integrating digital monitoring technologies and innovative grid systems is reshaping Nigeria's gas-to-power (GTP) landscape, offering opportunities to enhance operational efficiency and reliability. Innovations such as real-time data analytics, Internet of Things (IoT) sensors, and artificial intelligence (AI)-based predictive maintenance are increasingly being deployed to minimize downtime and improve plant performance [74, 75]. These technologies allow operators to anticipate equipment failures and schedule maintenance proactively, a critical need in Nigeria's power sector, where frequent equipment breakdowns disrupt supply.

A notable advancement is the implementation of Supervisory Control and Data Acquisition (SCADA) systems, which enable remote monitoring and diagnostics of gas power plants. SCADA systems provide real-time insights into parameters such as turbine temperature, pressure, and fuel flow, allowing for prompt fault detection and optimized fuel use. In Nigeria, where manual monitoring often leads to delayed responses and increased operational inefficiencies, SCADA offers a reliable, automation-based alternative to reduce human error and response times significantly.

However, the successful use of these digital tools is constrained by several systemic challenges. One key limitation is Nigeria's unreliable internet and communication infrastructure, particularly in remote areas where gas power plants are often located. Inconsistent bandwidth and power outages can disrupt data transmission and reduce the effectiveness of digital monitoring tools. Additionally, the shortage of skilled personnel trained in handling advanced digital systems increases dependence on foreign technical support, thereby raising operational costs and reducing sustainability.

Nigeria's gradual move towards smart grid integration aims to improve electricity distribution efficiency and reduce technical and non-technical losses, which remain among the highest in Sub-Saharan Africa. Smart grids facilitate better load management, real-time feedback, and decentralized energy generation—capabilities essential in managing the country's fragmented and overstressed power infrastructure. Furthermore, the deployment of Gas Turbine Optimization Software (GTOS) has enabled more accurate control of combustion dynamics, resulting in lower fuel consumption and increased power output [76, 77].

Despite these advantages, Nigeria's rollout of innovative grid technologies faces significant institutional and logistical hurdles. Aging transmission infrastructure, regulatory uncertainty, and limited investment in grid modernization slow the adoption of intelligent energy systems. Moreover, environmental conditions such as high temperatures and humidity can degrade the performance of sensitive electronic components used in smart meters and digital sensors, increasing the need for robust, climate-resilient hardware solutions.

In summary, digital monitoring and smart grid technologies promise to improve Nigeria's gas-to-power sector's efficiency, reliability, and sustainability. However, realizing their full potential requires concerted efforts to strengthen digital infrastructure, build local technical capacity, and create a supportive regulatory environment tailored to the country's operational realities.

3.3.5. Carbon Capture and Storage (CCS) Technologies

As Nigeria seeks to balance its growing energy demands with climate commitments, carbon capture and storage (CCS) technologies are emerging as a potential strategy to reduce the environmental footprint of gas-fired power plants. CCS works by capturing carbon dioxide (CO_2) emissions at the source, typically at power generation facilities and transporting the compressed gas for underground storage, often in depleted oil and gas reservoirs [78, 79].

In the Nigerian context, CCS holds several notable advantages. First, the country's extensive oil and gas infrastructure, including pipelines and depleted reservoirs, provides a foundation for CO_2 transport and storage. This existing infrastructure could lower capital investment requirements compared to countries without such resources. Additionally, implementing CCS aligns with national policy goals such as reducing gas flaring, a major source of emissions, and achieving the country's net-zero target by 2060 [80].

Pilot initiatives like the Shell Nigeria CCS Feasibility Study are evaluating the economic and technical feasibility of large-scale deployment. These efforts mark an important step toward integrating CCS into Nigeria's broader climate strategy and may serve as a model for other hydrocarbon-producing nations in Africa.

However, the path to widespread CCS adoption is fraught with challenges specific to Nigeria. One major limitation is the high cost and energy intensity of CCS systems, which can reduce the overall efficiency of power plants, an issue in a country already grappling with energy shortages and high generation costs. Additionally, Nigeria lacks the technical expertise and regulatory framework necessary to support large-scale CCS implementation. The country's research and academic institutions are still developing the advanced geotechnical knowledge required to assess and manage

long-term CO_2 storage risks.

Environmental and social considerations also pose obstacles. Nigeria's history of environmental degradation and weak regulatory enforcement raises concerns about the safety and integrity of underground CO_2 storage. Communities located near proposed storage sites may resist projects due to fears of leakage or seismic activity, particularly in the oil-rich Niger Delta, where trust in energy companies remains low.

Moreover, the limited availability of reliable data on Nigeria's geological formations hinders accurately identifying safe and suitable storage sites. Without detailed subsurface mapping, the risk of leakage or storage failure increases, potentially undermining environmental benefits and public confidence in CCS projects.

While CCS technologies offer Nigeria a pathway to reduce emissions from its gas-to-power sector and meet international climate obligations, their successful deployment requires overcoming significant financial, technical, and social barriers. Targeted investment in capacity building, regulatory development, and geological research will be essential to unlocking CCS's full potential within the Nigerian energy landscape.

3.3.6. Future Prospects and Strategic Recommendations

To accelerate technological advancements in Nigeria's gas-to-power sector, the following strategies are recommended:

1. Investment in R&D: Increased funding for research into next-generation gas turbines, CCS, and smart grid solutions.
2. Public-Private Partnerships (PPPs): Government and private investors collaborate to finance new technologies.
3. Capacity Building: Training programs for engineers and technicians to improve technical expertise.
4. Regulatory Reforms: Streamlining approval processes for new technologies to encourage faster adoption.

4. Challenges in Natural Gas Utilization

Despite Nigeria's vast natural gas reserves and significant efforts to harness this resource for power generation, numerous challenges hinder its effective utilization. These challenges range from infrastructure deficits and regulatory inconsistencies to financial constraints and environmental concerns. Addressing these barriers is crucial for optimizing natural gas utilization and ensuring energy security in Nigeria.

4.1. Infrastructure Deficits

A major challenge in Nigeria's natural gas utilization is inadequate gas processing, transportation, and distribution infrastructure. Many power plants rely on outdated or inefficient pipelines, leading to frequent supply disruptions and inefficiencies [5, 45]. Nigeria's gas pipeline network is underdeveloped compared to its production potential, resulting in gas flaring, shortages, and transmission losses [49, 81]. Existing power plants in Nigeria often operate below capacity due to inconsistent gas supply, which is exacerbated by pipeline vandalism and insufficient investment in pipeline expansion [82, 83]. Proposed solutions include expanding and modernizing gas pipeline networks, strengthening security measures to prevent vandalism, and increasing public-private partnerships (PPPs) for gas infrastructure development.

4.2. Policy and Regulatory Challenges

Nigeria's natural gas and power sectors are plagued by regulatory inconsistencies and bureaucratic bottlenecks, slowing investment and development. The lack of a clear, stable legal framework has led to delays in critical projects. Frequent policy changes create uncertainty for investors, discouraging long-term commitments in gas-to-power projects [84, 85].

Implementing the Petroleum Industry Act (PIA) 2021 was a significant step toward restructuring the gas sector, yet gas pricing issues and subsidy-related disputes continue to undermine industry growth [86, 87]. The dual ownership of electricity and gas regulation between the Nigerian Electricity Regulatory Commission (NERC) and the Department of Petroleum Resources (DPR) has also created overlapping responsibilities, resulting in inefficiencies. Possible solutions are full implementation of the PIA to enhance investment incentives, regulatory streamlining to ensure efficient licensing and project approvals, and implementing competitive and transparent gas pricing policies.

4.3. Financial Constraints

Gas-to-power projects in Nigeria require significant capital investments, but funding limitations have hindered the sector's expansion. Many financial institutions are reluctant to finance energy infrastructure due to high investment risks, policy uncertainties, and currency fluctuations [88, 89]. Additionally, the Nigerian government subsidies on electricity tariffs have created unsustainable revenue models for gas suppliers [90, 91].

The absence of cost-reflective tariffs in the electricity market makes it difficult for power producers to recover investment costs, leading to financial struggles and inadequate infrastructure maintenance [92, 93]. Nigeria's credit rating and foreign exchange volatility further impact investors' ability to secure loans for gas projects. Proposed solutions include introducing cost-reflective gas pricing mechanisms, strengthening financial incentives, and tax breaks for gas-based power projects, and increasing access to international funding and development grants.

4.4. Gas Flaring and Environmental Concerns

Despite regulatory efforts, gas flaring remains a significant environmental and economic challenge in Nigeria. Approximately 25% of the gas produced is still flared, leading to the loss of valuable resources and contributing to greenhouse gas emissions [26, 94]. The Nigerian Gas Flare Commercialization Program (NGFCP) was launched to address this issue, but progress has been slow due to investment constraints and operational challenges [52, 95].

Concerns over methane leakage, land degradation, and air pollution pose environmental and health risks to communities near gas facilities [94, 96]. The impact of carbon emissions from gas-fired power plants also raises questions about Nigeria's commitment to the Paris Climate Agreement and the Net-Zero 2060 target [97, 98]. Proposed solutions to this challenge include accelerated implementation of the NGFCP to reduce flaring, investment in carbon capture and storage (CCS) technologies, and strengthening environmental policies to mitigate gas-related pollution.

4.5. Security Challenges and Vandalism

Pipeline vandalism, insurgent attacks, and community unrest in the Niger Delta region pose major threats to Nigeria's gas supply chain. Frequent disruptions due to sabotage and illegal tapping of pipelines result in supply shortages for power plants and financial losses for gas producers [99, 100]. The instability in oil-producing regions further discourages investment in gas infrastructure [101]. Possible solutions include strengthening pipeline surveillance and security measures, engaging with local communities to foster resource management partnerships, and deploying advanced monitoring technologies (e.g., drones, AI surveillance) to detect and prevent vandalism.

4.6. Limited Technological Adoption

Nigeria's gas-to-power sector lags in adopting modern energy technologies, limiting operational efficiency and sustainability. Outdated power plants and gas processing units often experience frequent breakdowns, resulting in an unreliable electricity supply [22, 102]. The lack of investments in innovative grid technology, digital monitoring systems, and energy storage solutions further constrains efficiency.

The adoption of Liquefied Natural Gas (LNG) mini-grid solutions and floating LNG facilities in Nigeria has been slow due to high setup costs and regulatory hurdles [73]. Nigeria's ability to utilize natural gas without technological advancements remains limited. Proposed solutions include incentivizing research and development (R&D) in energy technology, encouraging public-private partnerships for technology transfer, and implementing innovative grid solutions for efficient gas distribution and electricity transmission.

5. Policy and Strategic Recommendations

The effective utilization of Nigeria's abundant natural gas resources for power generation requires comprehensive policy interventions and strategic actions. Despite the country's vast gas reserves, several challenges, including infrastructure deficits, regulatory bottlenecks, financial constraints, and environmental concerns, continue to hinder the sector's growth [55]. Addressing these issues requires policy reforms, investment incentives, and technological advancements to ensure a sustainable and efficient gas-to-power industry. This section outlines key policy and strategic recommendations to enhance natural gas utilization for power generation in Nigeria.

5.1. Strengthening Infrastructure Development

A well-developed gas infrastructure network is critical for efficiently utilizing natural gas for power generation. Nigeria's limited gas processing and transportation infrastructure contributes to supply shortages, increased flaring, and inefficient power generation [103]. To address these challenges, the following measures should be implemented:

1. Expansion of gas pipeline networks: The completion of critical projects such as the Ajaokuta-Kaduna-Kano (AKK) pipeline and the Obiafu-Obrikom-Oben (OB3) pipeline should be prioritized to improve gas transmission to power plants.
2. Development of gas storage and processing facilities: Increasing gas storage capacity can help mitigate supply disruptions, particularly during maintenance periods or emergency shutdowns.
3. Adoption of mini-LNG and floating LNG solutions: These alternative gas supply options can help provide off-grid power solutions for rural and industrial areas with limited grid access.

Investing in modern gas infrastructure will enhance the reliability of gas supply for power generation, improve energy security, and reduce gas flaring.

5.2. Enhancing Policy Implementation and Regulatory Efficiency

Regulatory inconsistencies and overlapping responsibilities between government agencies discourage investment and slow project execution. To streamline policy implementation and regulation, the following strategies are recommended:

1. Full implementation of the Petroleum Industry Act (PIA) 2021: This law should be fully enforced to remove regulatory uncertainties, promote cost-reflective pricing, and attract private sector investments in gas-to-power projects.
2. Harmonization of energy sector regulations: The roles of the Nigerian Electricity Regulatory Commission (NERC) and the Nigerian Midstream and Downstream Petroleum

Regulatory Authority (NMDPRA) should be clearly defined and streamlined to avoid duplication of functions.

3. Simplification of licensing and permit processes: The government/NMDPRA should reduce bureaucratic delays by fast-tracking approvals for gas infrastructure projects, improve the ease of license issuance, ensure transparency in licensing procedures and collapse the multiplicity of licenses, such as License To Establish (LTE), License To Construct (LTC), License To Operate (LTO), and Pipeline License (OPL or PLL), permit to introduce hydrocarbon.

Improving the regulatory landscape will create a more stable and predictable investment climate, accelerating the deployment of gas-to-power projects.

5.3. Promoting Financial Incentives and Investment Mobilization

The high capital costs of natural gas infrastructure and power plant development often discourage private sector participation. To attract local and foreign investments, the following financial strategies should be considered:

1. Introduction of tax incentives and subsidies: The government should provide tax holidays, duty waivers on gas infrastructure equipment, and subsidized loans to incentivize investments in gas infrastructures and gas-fired power plants.
2. Public-private partnerships (PPPs): Encouraging joint ventures between the government and private investors can enhance funding for critical gas projects.
3. Facilitation of international financing: Nigeria should leverage global climate finance initiatives such as the World Bank's Energy Sector Management Assistance Program (ESMAP) and the African Development Bank's (AfDB) Sustainable Energy Fund for Africa (SEFA) to secure funding for gas-based power projects.
4. Cost-reflective electricity tariffs: Implementing market-driven gas and electricity pricing will generate revenue and ensure financial sustainability for gas suppliers and power producers.

A well-structured financial framework will unlock funding opportunities for natural gas development, enhancing electricity generation capacity and reliability.

5.4. Addressing Environmental and Gas Flaring Concerns

Despite Nigeria's commitment to reducing gas flaring, significant gas volumes are still wasted, contributing to environmental degradation and climate change. The following measures can help mitigate environmental risks:

1. Full enforcement of the Nigerian Gas Flare Commercialization Program (NGFCP): This program should be accelerated to eliminate gas flaring through gas capture and utilization projects.
2. Investment in carbon capture and storage (CCS) technologies: The government should support the deployment of CCS solutions in gas-fired power plants to reduce carbon emissions.
3. Promotion of renewable energy integration: A balanced energy mix combining natural gas and renewable energy sources (such as solar, wind, and hydro) can reduce Nigeria's carbon footprint while ensuring a stable power supply.

Tackling environmental challenges will align Nigeria's natural gas utilization strategy with global climate commitments, ensuring a sustainable energy future.

5.5. Strengthening Security and Reducing Vandalism

Pipeline vandalism, oil theft, and insurgency pose major threats to the stability of the natural gas supply in Nigeria. To enhance security and operational reliability, the following steps should be taken:

1. Deployment of advanced security technologies: Drones, AI-based monitoring systems, and smart sensors can help detect and prevent pipeline vandalism.
2. Community engagement and stakeholder partnerships: Strengthening corporate social responsibility initiatives in host communities can foster cooperation and reduce sabotage risks.
3. Government-led security interventions: Establishing a dedicated task force to protect critical gas infrastructure will enhance supply chain security.

6. Conclusion

This paper examines the progress of natural gas utilization in Nigeria's power sector, assessing its status, recent technological advancements, and key challenges. Nigeria's substantial natural gas reserves offer a unique opportunity to transform the power sector, drive industrial growth, and enhance national energy security. While significant progress has been made in expanding gas-fired power generation, modernizing gas infrastructure, and adopting advanced technologies, critical barriers ranging from infrastructure gaps and policy inefficiencies to environmental and security concerns continue to limit the full potential of natural gas utilization in power generation.

To address these challenges and accelerate progress, the following specific, stakeholder-targeted recommendations are proposed:

1. The Nigerian Government:
   (1) Establish a clear and enforceable gas-to-power policy roadmap with defined timelines, performance indicators, and cross-agency coordination to improve policy consistency and investor confidence.
   (2) Expand domestic gas infrastructure investment

through public-private partnerships (PPPs), particularly in pipeline interconnectivity, gas metering, and small-scale LNG (mini-LNG) transport solutions to serve off-grid and industrial clusters.

(3) Strengthen regulatory institutions such as the Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) to ensure timely licensing, transparent pricing mechanisms, and dispute resolution frameworks.

(4) Implement fiscal incentives, including tax breaks, tariff adjustments, and sovereign guarantees to de-risk long-term investment in gas power projects, especially in rural and underserved regions.

2. Industry Actors:

(1) Adopt modular and scalable gas power technologies to reduce capital intensity and deployment time in off-grid and semi-urban areas.

(2) Integrate digital monitoring, predictive maintenance, and energy management systems to enhance operational efficiency and reduce unplanned outages in gas plants.

(3) Collaborate with academic and research institutions to localize technology development and build capacity in carbon capture and gas turbine optimization areas.

(4) Develop community engagement frameworks to mitigate risks associated with host community opposition and pipeline vandalism, particularly in the Niger Delta.

3. Local and International Investors:

(1) Prioritize investment in small- to medium-scale gas-to-power projects where risks are lower and return on investment is faster, primarily through captive power arrangements for industrial zones.

(2) Explore opportunities in emerging segments such as floating LNG (FLNG), mini-LNG, and waste heat recovery systems, which offer flexibility and environmental advantages.

(3) Support climate-aligned energy projects that qualify for green financing, carbon credits, or sustainability-linked loans to reduce exposure to environmental risks and enhance project bankability.

4. Avenues for Future Research:

Further scholarly inquiry is needed to support evidence-based policy and investment decisions. Priority areas include:

(1) Techno-economic analysis of decentralized gas-to-power systems in rural Nigeria.

(2) Geospatial modeling of optimal gas infrastructure expansion to inform investment planning.

(3) Environmental risk assessments of carbon capture and storage (CCS) and mini-LNG transport in tropical climates.

(4) Policy impact evaluations to assess the effectiveness of recent regulatory reforms in the gas and power sectors.

By taking coordinated, evidence-informed, and stakeholder-specific actions, Nigeria can unlock natural gas's full potential as a catalyst for sustainable power generation. Doing so will improve energy access and industrial productivity and position Nigeria as a leader in the clean energy transition among resource-rich developing economies.

Abbreviations

AfDB	African Development Bank's
AG	Associated Gas
AI	Artificial Intelligence
AKK	Ajaokuta-kaduna-kano Pipeline
BCM	Billion Cubic Meter
CCGT	Combined-cycle Gas Turbines
CCPP	Combined-cycle Power Plants
CCS	Carbon Capture and Storage
CGPF	Central Gas Processing Facility
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DPR	Department of Petroleum Resources
EGPP	Escravos Gas Processing Plant
ELPS	Escravos-lagos Pipeline System
ESMAP	Energy Sector Management Assistance Program
FEED	Front End Engineering Design
FLNG	Floating Liquefied Natural Gas
GTOS	Gas Turbine Optimization Software
GTP	Gas-to-power
IoT	Internet of Things
IPP	Independent Power Plant
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LTC	License to Construct
LTE	License to Establish
LTO	License to Operate
MTPA	Million Tonnes per Annum
MW	Mega Watt
NAG	Non-associated Gas
NERC	Nigerian Electricity Regulatory Commission
NGEP	National Gas Expansion Programme
NGFCP	Nigeria Gas Flare Commercialization Program
NGMP	Nigerian Gas Master Plan
NGP	National Gas Policy
NGTNC	Nigerian Gas Transportation Network Code
NMDPRA	Nigerian Midstream and Downstream Petroleum Regulatory Authority
NNPC	Nigerian National Petroleum Company Limited
NUPRC	Nigerian Upstream Petroleum Regulatory Commission
OB3	Obiafu-obrikom-oben
OPL	Oil Pipeline License

PIA	Petroleum Industry Act
PLL	Pipeline License
PPI	Presidential Power Initiative
PPP	Public-private Partnerships
PSRP	Power Sector Recovery Program
Q3	Quarter Three (July - September)
Q4	Quarter Four (October – December)
R&D	Research and Development
SCADA	Supervisory Control and Data Acquisition
SEFA	Sustainable Energy Fund for Africa
TCF	Trillion Cubic Feet
TSCF	Trillion Standard Cubic Feet

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References

[1] Gürsan, C. & de Gooyert, V. The systemic impact of a transition fuel: Does natural gas help or hinder the energy transition?. Renewable and Sustainable Energy Reviews. 2021, 138, 110552. https://doi.org/10.1016/j.rser.2020.110552

[2] Strielkowski, W., Civín, L., Tarkhanova, E., Tvaronavičienė, M., & Petrenko, Y. Renewable energy in the sustainable development of electrical power sector: A review. Energies. 2021, 14(24), 8240. http://dx.doi.org/10.3390/en14248240

[3] Finkelman, R. B., Wolfe, A., & Hendryx, M. S. (2021). The future environmental and health impacts of coal. Energy Geoscience. https://doi.org/10.1016/j.engeos.2020.11.001

[4] Ogbomida, E., Mustapha, A., Emeribe, C., Ezemonye, L., & Ajieh, M. Perspective Chapter: Unlocking Energy and Natural Resources for Sustainable Development in Nigeria–The Role of Energy. Reducing Carbon Footprint in Different Sectors for Sustainability. 2024, 147. https://www.intechopen.com/chapters/1180056

[5] Mmesomachukwu, C. U. P., & Uchechukwu, O. N. Improving Natural Gas Utilization in Nigeria: An Analysis of the Domestic Gas Industry From 2010-2022. In SPE Nigeria Annual International Conference and Exhibition (p. D021S010R001). SPE. 2024. https://doi.org/10.2118/221746-MS

[6] Olujobi, O. J., Okorie, U. E., Olarinde, E. S., & Aina-Pelemo, A. D. Legal responses to energy security and sustainability in Nigeria's power sector amidst fossil fuel disruptions and low carbon energy transition, Heliyon. 2023.

[7] Emetere, M. E., Agubo, O., & Chikwendu, L. Erratic electric power challenges in Africa and the way forward via the adoption of human biogas resources. Energy Exploration & Exploitation. 2021, 39(4), 1349-1377. https://doi.org/10.1177/01445987211003678

[8] Iwuchukwu, E. E. Evaluating the Potential of Natural Gas in Achieving the Nigeria Energy Transition Plan. In SPE Nigeria Annual International Conference and Exhibition (p. D031S020R002). SPE. 2024, Lagos Nigeria. https://doi.org/10.2118/221630-MS

[9] Ugolo, J. U., Iwegbu, M. C., & Onwuchei, A. Comparative Study for the Successful Implementation of Compressed Natural Gas (CNG) Solution in Developed and Developing Countries. In SPE Nigeria Annual International Conference and Exhibition (p. D032S030R005). SPE. 2024. https://onepetro.org/SPENAIC/proceedings-abstract/24NAIC/24NAIC/547855

[10] Oyewunmi, T. Natural gas in a carbon-constrained world: Examining the role of institutions in curbing methane and other fugitive emissions. LSU J. Energy L. & Resources. 2021, 9(1), https://ssrn.com/abstract=3550292

[11] Eneyo, G. A. (2022). Legal framework for utilisation and emissions-impact mitigation from natural gas production: the case for Nigeria. core.ac.uk.

[12] Allen-Ameri, J. D. Design and Economic Evaluation of Fiscal Regime for Associated Gas Development Under Production Sharing Contracts in Nigeria's Deep. [Doctoral Thesis, University of Ibadan, Nigeria, 2023]. 140.105.46.132.

[13] Adamu, A. & Rabe Darma, M. Inland Natural Gas Consumption and Real Economic Growth in Nigeria: ARDL Cointegration Test, Journal of Economics and Sustainable Development. 2016, 7(8), 186-206. JESD-Vol. 7 No. 8, 2016.

[14] Mohammed, J. I. (2022). An investigation into the effectiveness of the design and enforcement of Nigeria's anti-gas flaring law and policy regimes, and the considerations of measures that could improve environmental regulatory compliance. Doctoral Thesis, Robert Gordon University, Aberdeen, Scotland. https://doi.org/10.48526/rgu-wt-1893017

[15] BP Statistical Review of World Energy June, 2017. Available at: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-statistical-review-of-world-energy-2017-full-report.pdf (accessed 17 March 2025).

[16] Nigerian Upstream Petroleum Regulatory Commission (NUPRC). 2023 Annual Report. https://www.nuprc.gov.ng/wp-content/uploads/2024/04/UPDATED-2023-NUPRC-ANNUAL-REPORT.pdf

[17] Nnodim, O. (2014). An evaluation of the adequacy of Nigeria's gas policies to meet domestic gas supply and infrastructural development challenges. Master thesis, The Robert Gordon University, Aberdeen, UK 2014. http://dx.doi.org/10.13140/RG.2.2.19368.67844/1

[18] Ingwe, R. The Nigerian Gas Masterplan, Investment Opportunities, Challenges, Issues Affecting Power Sector: An Analysis. Studia Universitatis Babeș-Bolyai Geographia. 2014, 59(2), 115–124. https://www.researchgate.net/publication/278849838_THE_NIGERIAN_GAS_MASTER-PLAN_INVESTMENT_OPPORTUNITIES_CHALLENGES_ISSUES_AFFECTING_POWER_SECTOR_AN_ANALYSIS

[19] Eko-Raphaels, M. U., Aruwei, P., Enaruna, D. V., Ajiboye, A. O., & Apinoko, R. Natural Gas Logistics, Utilization and Impact on Nigeria's Economic Health: A Simple Empirics. Int. Res. J. Financ. Econ. 2022, 10, 98-105. researchgate.net

[20] Abu, R. N. Gas flaring reduction in Nigeria in context of carbon dioxide (CO_2) reduction and utilisation requirements [Doctoral thesis, University of Cranfield, UK, 2021]. cranfield.ac.uk.

[21] Diala, J. O., Nteegah, A., Ezurum, A. U., & Joseph, A. Gas Sector Development in Nigeria: The Nexus between Gas Supply, Price, Utilization, Taxation and Economic Growth. Asian Journal of Economics, Finance and Management. 2024, 6(1), 288–304. https://www.journaleconomics.org/index.php/AJEFM/article/view/238

[22] Babatunde, O., Buraimoh, E., Tinuoye, O., Ayegbusi, C., Davidson, I., & Ighravwe, D. E. Electricity sector assessment in Nigeria: the post-liberation era. Cogent Engineering. 2023, 10(1), 2157536. http://dx.doi.org/10.1080/23311916.2022.2157536

[23] Edomah, N. The governance of energy transition: lessons from the Nigerian electricity sector. Energy. Sustainability and Society. 2021, 11(40), 1-12. https://doi.org/10.1186/s13705-021-00317-1

[24] Oduka, U. M., Odutola, T. O., Oriji, A. B. Impact of Domestic Natural Gas Utilization on the Power Sector in Nigeria. American Journal of Energy Engineering. 2025, 13(1), 9-22. https://doi.org/10.11648/j.ajee.20251301.12

[25] Aniebo, I. N., & Mogbo, O. Energy Economics of Midstream and Downstream Petroleum Sectors in Nigeria: A Review of Potential Optimizations. In SPE Nigeria Annual International Conference and Exhibition. 2024, Lagos, Nigeria. https://doi.org/10.2118/221747-MS

[26] Omobolanle, O. C., & Ikiensikimama, S. S. Gas flaring: Technicalities, challenges, and the economic potentials. Environmental Science and Pollution Research. 2024, 31(28), 40838-40850. https://link.springer.com/article/10.1007/s11356-024-33784-y

[27] Ukhurebor, K. E., Aigbe, U. O., Onyancha, R. B., Athar, H., Okundaye, B., Aidonojie, P. A.,... & Darmokoesoemo, H. Environmental influence of gas flaring: Perspective from the Niger Delta region of Nigeria. Geofluids. 2024; 1, 1321022. https://doi.org/10.1155/2024/1321022

[28] Ojomah N, (2024). From Policy to Pipeline: The Evolution of Nigeria's Gas Sector in the Decade Of Gas. The Firma Advisory. Available online at: https://thefirmaadvisory.com/new-blog/2024/5/2/from-policy-to-pipeline-the-evolution-of-nigerias-gas-sector-in-the-decade-of-gas#:~:text=%E2%80%9CFrom%20Policy%20to%20Pipeline:%20The,utilisation%20and%20supporting%20economic%20growth (accessed 18 March 2025).

[29] Nigerian National Petroleum Corporation (NNPC). The Nigerian Gas Master Plan Status Update (2007). Available from: https://nesgroup.org/download_policy_drafts/Presentation%20on%20the%20Nigerian%20Gas%20Master%20Plan_1661855587.pdf (accessed 11 May 2025).

[30] Banwo & Ighodalo. Synopsis of the 2017 National Gas Policy. 2017. https://banwo-ighodalo.com/assets/resources/07f626c12fbf7095122004ad5eaa137e.pdf

[31] Timiyan, M. Nigeria's Economic Reliance on Fossil Fuels: Issues and Proposals for Transition to Renewable Energy. Doctoral Thesis, Alliant International University, San Diego, USA, 2022. https://www.proquest.com/openview/f78996310e11ccbaca31fbcb45b8bf94/1?cbl=18750&diss=y&pq-origsite=gscholar

[32] Gava, E., Lawrence, S. A., Eyesan, O. M., Mupa, M. N., & Inadagbo, K. Optimizing Supply Chain and Logistics in Industrialization: A Strategic Analysis of Natural Gas Metrics and Nigeria's Impact on Europe Energy Security, Iconic Research and Engineering Journals. 2024, 8(3), researchgate.net

[33] Olawuyi, D. S. (2022). The role of natural gas in a just and equitable energy transition. In The Palgrave Handbook of Natural Gas and Global Energy Transitions. Palgrave Macmillan, Cham: Springer International Publishing. Switzerland; 2022, pp. 73-95. http://dx.doi.org/10.1007/978-3-030-91566-7_3

[34] Dike, S. C. & Osinachi-Nwandem, S. E. Regulatory framework governing gas operations and utilization in the Nigerian petroleum industry, African Journal of International Energy & Environmental Law. 2023, 7(01), 29-40. https://ajieel.com/index.php/a/article/view/47

[35] Okokpujie, I. P., Tartibu, L. K., & Tukuru, I. O. Enhancing the Use of Renewable Energy in the Transportation Sector of Nigeria. International Journal of Transport Development and Integration. Integration. 2023. 177-198. https://doi.org/10.18280/ijtdi.070303

[36] Oruwari, H. O., Obunwa, Q., Ahuchogu, J., & Ayuba, S. Energy Security and Sustainable Development of Nigeria's Oil and Gas Sector. In SPE Nigeria Annual International Conference and Exhibition (p. D031S015R006). SPE., Lagos, Nigeria, 2024. https://doi.org/10.2118/221651-MS

[37] Nigerian Electricity Regulatory Commission (NERC). Fourth quarter 2024, NERC quarterly reports. https://nerc.gov.ng/wp-content/uploads/2025/03/2024_Q4-Report.pdf

[38] Malami, M., Nwosi-Anele, A. S., & Iledare, O. Petroleum Industry Act 2021 and Natural Gas Development in Nigeria: Matters Arising. In SPE Nigeria Annual International Conference and Exhibition (p. D031S020R001). 2024, Lagos, Nigeria. https://doi.org/10.2118/221708-MS

[39] Areremi, A. C. & Emaviwe, C. The Evolution of Gas Development and Utilization in Nigeria. KB Law Scholars Journal. 2023. kblsp.org.ng.

[40] Statista (2024). Generation capacity of gas in Nigeria 2000-2022. Available from: https://www.statista.com/statistics/1307080/nigeria-installed-generation-capacity-of-gas/ (accessed 25 October 2024).

[41] Ojukwu, C. N. An Analysis of Redress Options for Nigerian Consumers in the Electricity Market. Doctoral Thesis, University of Leicester, UK, 2023. https://figshare.le.ac.uk/articles/thesis/An_Analysis_of_Redress_Options_for_Nigerian_Consumers_in_the_Electricity_Market/25650573/1/files/45753063.pdf

[42] Agusto & Co. (2023). The Nigerian Independent Electric Power Producers. Available from https://www.agustoresearch.com/report/2023-the-nigerian-independent-electric-power-producers/ (accessed 9 April 2025).

[43] Saturday, E. G. Nigerian power sector: a new structure required for effective and adequate power generation, transmission and distribution. Global Journal of Engineering and Technology Advances. 2021, 7(1), 006-018. https://doi.org/10.30574/gjeta.2021.7.1.0035

[44] Al-Ismail, F. S. A Comprehensive and Critical Review on Integrated Electric Power and Gas Networks. IEEE Access. 2024, 12, 143042–143057. http://dx.doi.org/10.1109/ACCESS.2024.3424890

[45] Adoghe, A. U., Adeyemi-Kayode, T. M., Oguntosin, V., & Amahia, I. I. Performance evaluation of the prospects and challenges of effective power generation and distribution in Nigeria. Heliyon. 2023, 9(3), 1-17 https://doi.org/10.1016/j.heliyon.2023.e14416

[46] Ihejirika, V. C., Iledare, O., & Adeogun, B. Economic Analysis of Gas to Power Project in Nigeria. In the proceeding of the Offshore Technology Conference. 2022, Houston, Texas, USA. https://doi.org/10.4043/31944-MS

[47] Ozowe, W., Daramola, G. O., & Ekemezie, I. O. Innovative approaches in enhanced oil recovery: A focus on gas injection synergies with other EOR methods. Magna Scientia Advanced Research and Reviews. 2024, 11(1), 311-324. https://doi.org/10.30574/msarr.2024.11.1.0095

[48] Adegbola, A. A., Ozigis, I. I., & Muhammad, I. D. Conceptual design of gas distribution pipeline network for estates in Nigeria. Nigerian Journal of Technology. 2021, 40(1), 25-36. https://doi.org/10.4314/njt.v40i1.5

[49] Bello, A. M. & Dauda, J. Assessment of Profitability and Impact of Risked Variables on the Viability of Ajaokuta-Kaduna-Kano Gas Pipeline. British Journal of Management and Marketing Studies. 2022, 5(3), 15-53. https://doi.org/10.52589/BJMMS

[50] Ekeinde, E. B and Okujagu, D. C. (2023). The Ajaokuta-Kaduna-Kano (AKK) Gas Pipeline and its Potential Impact on Industrialization in Northern Nigeria. International Journal of Innovative Analyses and Emerging Technology, 3(12), 13-20.

[51] Habib, M. & Congjiao, X. The Ajoukuta–Kaduna-Kano Natural Gas Pipeline Project. An Opportunity for The Nigerian Gas Sector, Proceedings of the International Petroleum and Petrochemical Technology Conference 2020, 2021. 43-57. http://dx.doi.org/10.1007/978-981-16-1123-0_5

[52] Abu, R., Patchigolla, K., & Simms, N. A review on qualitative assessment of natural gas utilisation options for eliminating routine Nigerian gas flaring, Gases. 2023, *3*(1), 1-24 https://doi.org/10.3390/gases3010001

[53] Ekpu, M & Obadina, O. Power Production using Natural Gas in Nigeria: Trends, Challenges and Way Forward, Nigerian Research Journal of Engineering and Environmental Sciences. 2020, 5(2), 873-885.

[54] Edjenekpo, L. Gas-to-Power and the Role of Gas Compression in the Nigerian Energy Industry: Current Challenges, Strategies and Solutions for Sustainable Development. SSRN Electronic Journal. 2014. 11(40), 1-12. http://dx.doi.org/10.2139/ssrn.2524058

[55] Adebayo, A. V., & Ainah, P. K. Addressing Nigeria's Electricity Challenges: Past, Present, And Future Strategies. American Journal of Applied Sciences and Engineering. 2024, 5(2), 1-16. https://doi.org/10.5281/zenodo.12633012

[56] Adegun, A., & Rufai, F. The Commercial Potentials of Underground Natural Gas Storage in Nigeria. In SPE Nigeria Annual International Conference and Exhibition. 2021, Lagos, Nigeria. https://doi.org/10.2118/207149-MS

[57] Biose, H. Gas Production and Utilization in Nigeria: A Long-term perspective. International Journal of Engineering Technologies and Management Research. 2019, 6(5). http://dx.doi.org/10.29121/ijetmr.v6.i5.2019.372

[58] Odumugbo, C. A. Natural Gas Utilisation in Nigeria: Challenges and Opportunities. Journal of Natural Gas Science and Engineering. 2010, 2(6), 310-316. https://doi.org/10.1016/j.jngse.2010.08.004

[59] Adekoya, O. O., Adefemi, A., Tula, O. A., Nwaobia, N. K., & Gidiagba, J. O. Technological innovations in the LNG sector: A review: Assessing recent advancements and their impact on LNG production, transportation and usage. World Journal of Advanced Research and Reviews. 2024, 21(1), 040-057. https://doi.org/10.30574/wjarr.2024.21.1.2685

[60] PGJ Online. (2025). Nigeria's NNPC, Partners to Build Five Mini-LNG Plants for Domestic Gas Supply. Available from: https://pgjonline.com/news/2025/january/nigerias-nnpc-partners-to-build-five-mini-lng-plants-for-domestic-gas-supply (accessed 9 April 2025).

[61] Rigzone (2025). Construction Starts on Five Mini-LNG Plants in Nigeria. Available from: https://www.rigzone.com/news/construction_starts_on_five_minilng_plants_in_nigeria-03-feb-2025-179507-article/#:~:text=The%20five%20will%20rise%20in,%2C%20industries%2C%20and%20businesses' (accessed 9th April 2025).

[62] Onagoruwa, G. A. The Financing Spectrum for LNG Projects. In The Palgrave Handbook of Natural Gas and Global Energy Transitions. Cham: Springer International Publishing, Switzerland; 2022, pp. 345-365. https://link.springer.com/chapter/10.1007/978-3-030-91566-7_14

[63] Riviera (2025). UTM Offshore's FLNG project is progressing towards final investment decision and execution phase. Available from: https://www.rivieramm.com/news-content-hub/news-content-hub/nigerias-pioneering-floating-lng-venture-83802#:~:text=Nigeria's%20UTM%20Offshore's%20Floating%20Liquefied,the%20first%20quarter%20of%202025 [accessed 9 April 2025].

[64] Enerdata (2024). China's Wison starts work on two FLNG projects in Nigeria, totalling 6 Mt/year. Available online at: https://www.enerdata.net/publications/daily-energy-news/chinas-wison-starts-work-two-flng-projects-nigeria-totalling-6-mtyear.html#:~:text=Transport-,China's%20Wison%20starts%20work%20on%20two%20FLNG,Nigeria%20totalling%206%20Mt%2Fyear&text=The%20Chinese%20company%20Wison%20New,Nigeria%20totalling%206%20Mt%2Fyear (accessed 9 April 2025).

[65] Emeke, C., Oluwadarasimi, E. F., Uwanaobong, A. I., & Maduewesi, C. Unlocking Non-Associated Gas Reservoirs to Power Future Energy Demands in Nigeria. International Journal of Latest Technology in Engineering, Management & Applied Science. 2024, 13(11), 51-60. *RePEc: bjb: journl: v: 13: y: 2024: i: 11: p: 51-60.*

[66] Adebayo, T. S., Kartal, M. T., & Ullah, S. Role of hydroelectricity and natural gas consumption on environmental sustainability in the United States: evidence from novel time-frequency approaches. Journal of Environmental Management. 2023, 328, 116987, https://doi.org/10.1016/j.jenvman.2022.116987

[67] Adebayo, T. S., Ullah, S., Kartal, M. T., Ali, K., Pata, U. K., & Ağa, M.*. Endorsing sustainable development in BRICS: The role of technological innovation, renewable energy consumption, and natural resources in limiting carbon emission. Science of the Total Environment. 2023, 859, 160181. https://doi.org/10.1016/j.scitotenv.2022.160181

[68] Onen, P. S., Zubo, R. H., Ali, N. T., Mokryani, G., Li, J. P., & Abd-Alhameed, R. Stochastic Expansion planning Model for a coordinated Natural gas and Electricity Networks Coupled with Gas-fired Generators, Power-to-Gas Facilities and Renewable Power, IEEE Access. 2024. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=10613399

[69] Remteng, C. (2022). A Review on the Role of Natural Gas in Nigeria's Energy Transition'. Environmental Network Journal. 2022, 1(3), 1-27. https://gwcnweb.org/wp-content/uploads/2023/08/ENJ-Vol1-Article3-Dec-2022.pdf

[70] Beagle, D., Moran, B., McDufford, M., & Merine, M. (2021). Heavy-Duty Gas Turbine Operating and Maintenance Considerations. GE Power Atlanta, GA. dcsmodule.com.

[71] Almajali, M. R., & Quran, O. A. Parametric study on the performance of combined power plant of steam and gas turbines. Journal of Thermal Science and Engineering Applications. 2021, 13(5), 051006. https://www.researchgate.net/publication/350458353

[72] Sammak, M., Smith, R., Kulkarni, P., N, R., & Sholes, J. Gas Turbine Combined Cycle System Integration with Carbon Capture Plant for Improved Value. In Turbo Expo: Power for Land, Sea, and Air, American Society of Mechanical Engineers. 2024, 87974, p. V005T06A008. https://doi.org/10.1115/GT2024-124227

[73] Oyewunmi, T. & Ehanmo, I. Emerging Trends in Resource-Rich Sub-Saharan Africa and a Spotlight on the Nigerian Transitional Energy Market. Tul. J. Int'l & Comp. L. 2021, 29(1), 1-26. https://journals.tulane.edu/jicl/article/download/3059/2848

[74] Osamonyi, O. & Thomas Temitope, G. (2023). Powering the Future: A Sustainable Reform Plan for Overcoming Transmission and Distribution Challenges in Nigeria Power Sector, African Scholar Journal of African Innovation & Advanced Studies (JAIAS-2). 28(2), 121-146. https://www.africanscholarpublications.com/wp-content/uploads/2023/04/AJAIAS_VOL28_NO2_MAR-2023-9.pdf

[75] Inyang, U. Nigeria's Gas-to-power Initiative: an Appraisal of the Journey So Far and the Way Forward. 2021. Available at SSRN 4722249. https://dx.doi.org/10.2139/ssrn.4722249

[76] Ekechukwu, D. E. (2024). Sustaining the grid with more renewable energy mix and smart grid applications, a case study of Nigeria's grid network, International Research Journal of Engineering and Technology (IRJET). 2024, 11(05). researchgate.net

[77] Ohanu, C. P., Rufai, S. A., & Oluchi, U. C. A comprehensive review of recent developments in smart grid through renewable energy resources integration. Heliyon. 2024. https://www.cell.com/heliyon/pdf/S2405-8440(24)01736-5.pdf

[78] Effiom, P. C., Effiom, S. O., Evareh, J. E., Uket, I. O., & Osim-Asu, D. Prospects of carbon capture technologies for enhanced oil recovery in Nigeria's oil and gas sector. International Journal of Engineering & Technology. 2024, 13(2), 286-293. http://dx.doi.org/10.14419/mftswe04

[79] Ogbo, O. G., Onuoha, D. C., & Odoh, C. Carbon Capture and Storage (CCS) in Nigeria: A Review of Challenges and Opportunities. British Journal of Multidisciplinary and Advanced Studies. 2024, 5(4), 1-18. https://doi.org/10.37745/bjmas.2022.04148

[80] Ibe, A. P., & Nwosi-Anele, A. S. Framework for Carbon-Capture and Storage (CCS) in Nigeria. In SPE Nigeria Annual International Conference and Exhibition. 2024, Lagos, Nigeria. https://doi.org/10.2118/221616-MS

[81] Edun, S. A., Olaniyi, T. K., & Lawani, K. Modelling the implications of oil pipeline vandalism on the Nigeria economy: a case study of Niger Delta region. International Journal of Innovative Business Strategies. 2023, 9(2), 592-602. http://dx.doi.org/10.20533/ijibs.2046.3626.2023.0075

[82] Jatto, A. L. A. Security and Theoretical Explanation of Pipeline Vandalism in Bayelsa State, Nigeria. In Oil and Gas Pipeline Infrastructure Insecurity: Vandalism, Threats, and Conflicts in the Niger Delta and the Global South. 2024, 131-186, Cham: Springer Nature Switzerland.

[83] Enumah, M. A. (2025). Analysis of Risk and Risk Management Strategies in Nigeria's Oil and Gas Industry. seahipublications.org

[84] Olujobi, O. J. Deregulation of the downstream petroleum industry: An overview of the legal quandaries and proposal for improvement in Nigeria, Heliyon. 2021. https://doi.org/10.1016/j.heliyon.2021.e06848

[85] Olujobi, O. J. Nigeria's upstream petroleum industry anti-corruption legal framework: the necessity for overhauling and enrichment, Journal of money laundering control. 2023, http://dx.doi.org/10.1108/JMLC-10-2020-0119

[86] Egbumokei, P. I., Dienagha, I. N., Digitemie, W. N., Onukwulu, E. C., & Oladipo, O. T. The role of digital transformation in enhancing sustainability in oil and gas business operations. International Journal of Multidisciplinary Research and Growth Evaluation. 2024, 5(5), 2582-7138.

[87] Ogbu, A. D., Eyo-Udo, N. L., Adeyinka, M. A., Ozowe, W., & Ikevuje, A. H. A conceptual procurement model for sustainability and climate change mitigation in the oil, gas, and energy sectors. World Journal of Advanced Research and Reviews. 2023, 20(3), 1935-1952. https://doi.org/10.30574/wjarr.2023.20.3.2304

[88] Ajia, A. T. Policy Challenges and Opportunities for Renewable Energy Development in Nigeria: A Systematic Review. African Journal of Environmental Sciences and Renewable Energy. 2025, 18(1), 115-137. http://afropolitanjournals.com/index.php/ajesre/article/download/660/558

[89] Anya, A. K., Ekakite, G. W., Anya, E. C., Krivins, A., & Jurgelāne-Kaldava, I. Entrepreneurial, Legal and Logistics Aspects of Gas in Nigeria. Journal of Entrepreneurship & Sustainability Issues. 2024, 11(4), 324-338. http://doi.org/10.9770/jesi.2024.11.4(20)

[90] Ogidi, T. S. Petroleum Subsidy and the Future of Nigeria'S Oil Sector: From Consumer Relief To Market Deregulation. *Journals for Social Sciences*. 2024, 1(10), 118-127. https://rapidjournals.com/wp-content/uploads/journal/published_paper/volume-1/issue-10/rjip_mPY3mMzp.pdf

[91] O., Nwaogwugwu, I., Vincent, O., Wale-Awe, O., Mesagan, E., & Ojapinwa, T. (2023). The socio-economics of the 2023 fuel subsidy removal in Nigeria. uni-muenchen.de

[92] Mohlin, K., Spiller, E., Tapia-Ahumada, K., & Unel, B. (2021). Cost-Reflective Residential Electricity Tariff Design: Synthesis of research findings on the impacts on customer bills, adoption of distributed energy resources and pollution. Environmental Defense Fund Economics Discussion Paper Series. 2021, EDF EDP, 21-07. https://dx.doi.org/10.2139/ssrn.3964982

[93] Ayansola, O. A., Ogundunmade, T. P., & Adedamola, A. O. Statistical Analysis of Cost Reflective Electricity Tariff and Distribution in Nigeria (A Study of Southwest States). Mod Econ Manag, 2. 2023. https://doi.org/10.53964/mem.2023005

[94] Obi, N., Akuirene, A., Bwititi, P., Adjene, J., & Nwose, E. U. Impact of gas flaring on communities in Delta region of Nigeria, narrative review part 1: environmental health perspective. International Journal of Scientific Reports. 2021, 7(3), 186-193. https://dx.doi.org/10.18203/issn.2454-2156.IntJSciRep20210548

[95] Babalola, A. A. & Olawuyi, D. S. Overcoming regulatory failure in the design and implementation of gas flaring policies: the potential and promise of an energy justice approach. Sustainability. 2022, 14(11), 6800. https://doi.org/10.3390/su14116800

[96] Odubo, T. C., & Kosoe, E. A. Sources of air pollutants: impacts and solutions. In Air Pollutants in the Context of One Health: The Handbook of Environmental Chemistry. 2024, 134. Springer, Cham. https://doi.org/10.1007/698_2024_1127

[97] Okoh, A. S. & Okpanachi, E. (2023). Transcending energy transition complexities in building a carbon-neutral economy: The case of Nigeria. Cleaner energy systems. 2023, 6, 100069. https://doi.org/10.1016/j.cles.2023.100069

[98] Kintner-Meyer, M., Conzelmann, G., Kim, H., Zhou, N., DeStephano, P., Durga, S.,... & Wright, E. The Net Zero World Initiative's Preliminary Analysis of Decarbonization Pathways for Five Countries. 2022. https://escholarship.org/content/qt5t38p25t/qt5t38p25t_noSplash_a9a6920bdfa32d068fe7c7383180bf01.pdf

[99] Jatto, A. L. A.*. The Effect of Oil and Gas Activities on Pipeline Vandalism: The Perspectives of Professional Operators. In Oil and Gas Pipeline Infrastructure Insecurity: Vandalism, Threats, and Conflicts in the Niger Delta and the Global South. 2024, 187-237. Cham: Springer Nature Switzerland.

[100] Atoyebi, T. A., Gomment, T. I., Yunusa, E., & Okeme, U. P. Perception and consequences of crude oil pipeline vandalism in Southern Ijaw local government of Bayelsa State, Nigeria, Journal of Xidian University. 2024, 18(8), 340-383. https://doi.org/10.5281/Zenodo.13303068

[101] Jatto, A. L. A.*[2]. Oil and Gas Pipeline Infrastructure and Sustainable Development in the Global South. In Oil and Gas Pipeline Infrastructure Insecurity: Vandalism, Threats, and Conflicts in the Niger Delta and the Global South. 2024, 37-53, Cham: Springer Nature Switzerland.

[102] Oruwari*, H., Salihu, A., & Obunwa, Q. The Role of Natural Gas in Energy Transition in Nigeria. In SPE Nigeria Annual International Conference and Exhibition (p. D031S020R007). SPE, Lagos, Nigeria, 2024. https://doi.org/10.2118/221768-MS

[103] Ojo, A., Adebanji, B., Fasina, T., Adeleye, S., & Abere, J. Integration of renewable energy with smart grid application into Nigeria's power network: Issues, challenges and Opportunities. European Journal of Engineering and Technology Research. 2022, 7(3), 18-24. http://dx.doi.org/10.24018/ejeng.2022.7.3.2792

Biography

Ugbede Mathew Oduka is a PhD (Petroleum Economics) student at the Emerald Energy Institute, University of Port Harcourt, Rivers State, Nigeria. He received the B.Eng degree in electrical and electronic engineering from the University of Agriculture Makurdi, Benue State, Nigeria, and M.Eng degree in communications engineering from the Federal University of Technology Owerri, Imo State, Nigeria. He worked briefly as a banker with First Atlantic Bank from 2004 to 2007. In March 2007, he later joined the Nigerian National Petroleum Company (NNPC) Ltd, and deployed to work with NNPC Gas Marketing Limited, a subsidiary of NNPC Limited, as an Instrument Engineer, Project Engineer, Project Lead, and Manager, delivering several gas transmission and distribution infrastructure projects. He is a Certified Project Management Professional and a Certified Gas Transmission Professional by Gas Technology Institute, USA. He is a registered engineer with Nigeria's Council for the Regulation of Engineering.

Toyin Olabisi Odutola is an Associate Professor in Petroleum and Gas Engineering and the Assistant Director at the Emerald Energy Institute, University of Port Harcourt (UNIPORT). She holds degrees in chemical and petroleum engineering from Ladoke Akintola University of Technology, African University of Science and Technology (AUST), and UNIPORT, all in Nigeria. A Flow Assurance specialist trained at the Colorado School of Mines, USA, she designed Nigeria's first hydrate flow loop, featured by the BBC in 2022. Dr. Odutola has three patents, a monograph, and numerous peer-reviewed publications. She was a visiting scholar at MIT and is a fellow of the MIT Empowering the Teachers Programme (MIT-ETT) and the Nigeria Science Leadership Programme (N-SLP). A COREN-registered engineer, she is an active member of several engineering societies and the recipient of multiple awards, including the 2024 SPE Africa Regional Distinguished Achievement Award for Petroleum Engineering Faculty.

Aleruchi Boniface Oriji is a professor of petroleum and gas engineering (drilling and well completion engineering) and the current director of the Emerald Energy Institute, University of Port Harcourt. He holds a B.Eng, M.Eng, and PhD in petroleum engineering from the University of Port Harcourt, Nigeria. He has over 15 years of teaching experience and is engaged in tutoring and knowledge transfer through teaching, research, and hands-on /industry practices. Before joining the University in 2010, he also had over twenty (20) years of working experience in the Oil and Gas Industry. He worked as a Drilling Fluids Engineer, Drilling Fluids Sales Engineer, Lead Drilling Fluids Engineer, Technical Field Supervisor, Technical Field Professional, International Senior Drilling Fluids Field Professional, and Senior Drilling Fluids Consultant. He is experienced in land, swamp, offshore, and deep offshore drilling operations. He also worked as a national/international staff member with Halliburton Nigeria / Halliburton Overseas.

Research Field

Ugbede Mathew Oduka: Microwave/RF power amplifier, low noise amplifier, green wireless systems, natural gas utilization, energy security, electricity generation, gas-to-power, petroleum and energy economics, emission reduction, and energy efficiency.

Toyin Olabisi Odutola: Hydrate mitigation, Flow assurance, petroleum economics, renewable energy, oil field chemicals.

Aleruchi Boniface Oriji: Oil and Gas wells Development, Gas production and utilization, Gas storage and transportation, Smart and intelligent well completion and localization of oil and Gas Materials.