

ABSTRACT

Nigeria, Africa's largest oil producer, faces the dual challenge of meeting growing energy demands while transitioning to a sustainable energy future. The economy's backbone, the oil and gas industry, is mostly dependent on fossil fuels for its operations, which raises carbon emissions and degrades the environment. Nigeria has a practical and strategic chance to preserve energy security, cut emissions, diversify its sources of income, cut operating expenses, and

INTEGRATING RENEWABLE ENERGY INTO NIGERIA'S OIL AND GAS SECTOR: A STRATEGIC PATHWAY FOR A SUSTAINABLE ENERGY FUTURE

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INTRODUCTION

As climate change continues to pose serious threats to ecosystems, businesses, and human livelihoods, worldwide decarbonization initiatives have accelerated in recent years. With 196 nations agreeing to keep global warming far below 2°C, ideally to 1.5°C over pre-industrial levels, the 2015 Paris Agreement was a turning point in international climate policy. A significant cut in greenhouse gas emissions is required to meet these goals, especially from carbon-intensive industries like gas and oil. The International Energy Agency (IEA) estimates that almost three-quarters of the world's CO₂ emissions are caused by the energy sector, with 42% of these emissions coming from the production of oil and gas (Bello, 2024).

These days, nations and businesses are spending money on a variety of decarbonization initiatives, such as increasing energy efficiency, adopting renewable energy sources, and carbon capture, utilization, and storage (CCUS). Energy businesses are coming under more pressure to implement cleaner practices in keeping with



comply with international sustainability objectives by incorporating renewable energy (RE) into the oil and gas industry as the global movement toward decarbonization gains traction. With an emphasis on uses including solar-powered rigs, hybrid microgrids, and green hydrogen, this article examines the possibilities of integrating renewable energy into Nigeria's oil and gas sector. It addresses challenges specific to Nigeria, including infrastructure limitations, regulatory barriers, and socio-economic constraints, and proposes a framework for adoption. Case studies, including a hypothetical 3MW solar microgrid for drilling operations in the Niger Delta, illustrate practical applications. The study emphasizes the transformative potential of renewable energy to enhance efficiency, sustainability, and resilience in Nigeria's oil and gas sector.

Keywords: Renewable energy integration, green hydrogen, hybrid micro-grids, decarbonization strategy, Nigerian oil and gas industry, energy transition policy.

these initiatives. The United States, Norway, and Saudi Arabia are among the major oil-producing countries that have set aggressive decarbonization goals. In keeping with the nation's goal of reducing emissions by 55% by 2030, Norway's oil corporation Equinor wants to cut emissions from the oil and gas sector by 40% by 2030 and reach 70% by 2040 (Bello, 2024).

Nigeria plays a significant role in the global oil and gas business as the continent's largest oil producer. More than 90% of Nigeria's value export earnings come from this industry, which also significantly boosts government revenue. Nigeria's oil and gas industry must strike a balance between environmental sustainability and economic growth. Nigeria is one of the top flaring countries in the world, contributing 11.5 million tons of CO₂ emissions yearly from gas flaring, one of the industry's most serious environmental problems (Adebayo *et al.*, 2024).

A key tactic to manage both environmental issues and financial challenges is incorporating renewable energy sources into oil and gas operations. This integration is significant because it has the potential to improve operating efficiency and long-term profitability in addition to reducing greenhouse gas emissions (Ezeh *et al.*, 2024, Ochulor *et al.*, 2024).

The Niger Delta, the heart of Nigeria's oil production, exemplifies the challenges and opportunities for renewable energy integration. Harsh environmental conditions, unreliable grid infrastructure, and socio-political tensions complicate operations, while abundant solar irradiance (5.5 kWh/m²/day) and potential for hybrid systems present untapped opportunities. This article examines how renewable energy can be integrated into Nigeria's oil and gas sector, focusing on technological applications,



challenges, and a strategic framework for sustainable energy adoption. According to research, renewable energy sources like wind and solar can lower operating costs, supplement traditional energy systems, and act as a hedge against the price volatility of fossil fuels (Baker et al., 2020). Additionally, incorporating renewable energy can assist oil and gas companies in meeting public expectations and regulatory obligations, enhancing their competitive positioning and company reputation. Previous studies have explored renewable energy adoption and sustainability transitions in Nigeria. However, there is limited focus on direct integration of renewable energy technologies within Nigeria's oil and gas operation. This study addresses this gap by examining both technical dimensions and policy aspect of renewable energy integration in Nigeria's oil and gas industry. To propose a practical framework for sustainable energy adoption in the industry, a policy and technical review approach is adopted, supported by illustrative case applications.

ENERGY DEMANDS OF NIGERIA'S OIL AND GAS SECTOR

The energy demands of Nigeria's oil sector can be categorized into:

Upstream: Fuel use and Power for Operations

Exploration and production (E&P) of natural gas and crude oil are together referred to as the upstream oil and gas sector. It is the initial phase of the value chain for oil and gas. It consists of offshore platforms, drilling rigs, FPSOs and other exploration and production infrastructure and equipment. Fuel oil, diesel, and gas are used by offshore platforms, drilling rigs, and FPSOs to generate electricity, heat, and mechanical power. In situations where grid power is unavailable, many installations rely on diesel or gas-turbine gensets. Operational intensity increases with deeper water and more intensive drilling activities. Compression (for gas gathering and injection) is a major electricity/gas demand driver

Practical Energy Loads in Nigeria Upstream Operations

Power generation on deep water assets, Large FPSOs installs utility power in the 50–150 MW range to run accommodation loads, compression, injection pumps and separation. Example, Bonga FPSO has 4 × 27 MW gas-turbine generators (108 MW installed). Flaring remains a material energy/emissions signal. Nigeria is still one of the world's higher flaring countries (though improving); the World Bank GGFR 2025 tracker notes global flaring has stagnated since 2023, showing why Nigeria's flare-to-value efforts matter for energy efficiency and gas availability.



Table 1: Energy Demand Matrix for Nigeria Upstream Operations

No	Process function	Energy carrier	Typical demand intensity	Operation implication in Nigeria
1	Exploration and drilling (Upstream)	Diesel, (gensets), fuel oil	20-30m ³ par rig (5,300-8000 US gal/day)	High dependence on imported diesel for offshore rigs; cost sensitivity to international oil prices.
2	Floating Production Storage and Offloading (FPSO) Utility Power	Associated gas, gas turbines	50-150 MW installed (bonga FPSO: 4×27MW)	Compression and water injection dominate base load; gas supply reliability directly affects uptime.
3	Gas Gathering & Reinjection	Compression (gas/electric)	0.25–0.35 kWh per Sm ³ compressed	Accounts for up to 40% of platform power demand; inefficiency leads to increased flaring risk.

Midstream: Processing and Gas Treatment

The second phase of the petroleum value chain is the midstream oil and gas industry, which is situated between the upstream (production and exploration) and downstream (refining and marketing) sectors. Its primary concentration is on the wholesale marketing, storage, and transportation of natural gas, crude oil, and refined goods. Both fuel gas and grid power are used by gas processing facilities, dehydration units, condensate stabilization, and pipelines.

Midstream Energy Footprint

Gas plants & “own-use” fuel. Processing (dehydration, condensate stabilization, NGL recovery) often runs on fuel gas from the inlet stream; in industry accounts this is recorded as lease/plant fuel, a material slice of gross withdrawals in many systems.

Table 2: Energy Demand Matrix for Nigeria Downstream Operations

No	Process function	Energy carrier	Typical demand intensity	Operation implication in Nigeria
1	Gas Processing (Midstream)	Fuel gas, grid power	5–8% of inlet stream consumed as plant/lease fuel	Dehydration, NGL recovery, and condensate stabilization significantly reduce net export volumes.



No	Process function	Energy carrier	Typical demand intensity	Operation implication in Nigeria
2	Pipeline Transportation	Fuel gas for compressors	2–3% of throughput used as pipeline fuel	Losses reduce Effective transmission; 5.8 Bscf/d capacity requires multiple high-pressure stations.
3	LNG Liquefaction (NLNG)	Gas turbines (>320 MW site power)	250–300 kWh per tonne LNG	Bonny LNG (22 Mtpa) consumes large volumes of gas for self-power, making efficiency upgrades critical.

Refining and Downstream

Following the upstream (exploration and production) and midstream (transportation and storage) sectors, the refining and downstream oil and gas sector is the last phase of the petroleum value chain. Its main objective is to transform natural gas and crude oil into completed goods and distribute them to consumers. Refineries need a lot of energy, including fuel derived from crude oil, outside electricity, and process heat. This includes new large-scale entrants like Dangote. Due to a lack of domestic refinery capacity, Nigeria has historically imported refined goods; however, recent refinery additions are altering internal fuel flows and demand patterns.

RENEWABLE ENERGY INTEGRATION

One increasingly practical way to cut emissions is to incorporate renewable energy into the oil and gas industry. Nigeria has enormous potential for solar energy, and incorporating solar energy into oil and gas operations for example, by using it to power certain components of onshore facilities or offshore rigs can significantly reduce emissions (Bello, 2024). However, in order for a regulated implementation considering how important this sector is to the Nigerian economy, a review of the government's commitment and policies is important (IRENA, 2023a, 2023b).

Policy and Regulatory Framework

Nigeria's Energy Transition Commitments

Nigeria has created an Energy Transition Plan (ETP) to direct activity across sectors and has made a public commitment to achieve net-zero by 2060. Opportunities for low-carbon development in the areas of industry, cooking, transportation, power, and, most importantly, the oil and gas sector are outlined in the ETP. To guarantee that the deployment of renewable energy is incorporated into the current hydrocarbon value chains, the ETP will need to be implemented with significant financial outlays and regulatory alignment (NUPRC, 2024).



Recent Regulatory Signals and Industry Shifts

A growing number of industry associations and regulators are coordinating licensing and permits with the demands of decarbonization. For instance, the upstream sector will likely face more stringent decarbonization requirements in the future due to new standards that demand proof of low-carbon strategies in licensing applications, including renewable energy initiatives. These changes in policy give operators incentives and responsibilities to implement renewable energy in field operations and facilities (John *et al.*, 2025; Oyedepo, 2012).

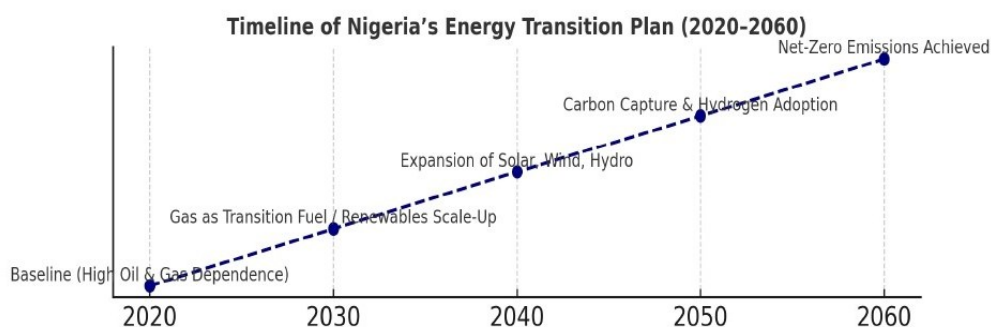
Rationale for Integrating Renewables into Oil & Gas Operations

Resilience and energy cost reduction: A large number of onshore and offshore plants run on gas or diesel power. Fuel consumption and running expenses can be decreased by waste heat recovery, solar photovoltaics, and hybrid systems (photovoltaic + batteries + gas backup) (Ozowe *et al.*, 2023).

Reduction of emissions: Using low-carbon electricity to electrify operations reduces Scope 1 and 2 emissions and can boost investor confidence and regulatory compliance (Adebayo *et al.*, 2024).

Value chain diversification: Renewables offer a chance to boost local value capture, diversify the country's energy sector, and generate jobs in manufacturing and operations (Ekechukwu & Eziefula, 2025).

Energy security and access: Hybrid systems can give host communities reliable electricity, enhancing their social license to operate and lowering conflicts within the community (Emodi & Boo, 2015; Nkalo, 2025).



Technical Pathways for Integration

Solar Energy: Reliance on gas/diesel gensets can be decreased by installing solar PV arrays at field camps, processing facilities, and remote flow stations in conjunction with battery energy storage systems (BESS). For instance, a 3MW solar microgrid could supply daytime drilling needs. Combining solar with battery storage and diesel backup ensures reliability in remote fields (Adebayo *et al.*, 2024).

Wind Energy: Nigeria's coastal regions, with wind speeds of 4-6 m/s, are suitable for offshore wind farms to power platforms (Ozowe *et al.*, 2023).



Green Hydrogen: Where natural gas is abundant, power-to-hydrogen using electrolyzers powered by RE can create hydrogen for use in refining, industrial processes, or for export. Hydrogen could replace natural gas in downstream processes, reducing emissions (Shao et al., 2025). Nigeria’s abundant solar resources could support cost-competitive hydrogen production by 2030 (Adeshina et al., 2024). Early pilot projects can explore blending hydrogen into existing processes and the economics of green hydrogen for specific use-cases.

Table 3: Technical Pathways for Renewable Energy Integration into Oil & Gas Operations

Technology	Integration Point	Technical Advantage	Operational Consideration	Potential Scale
Solar PV + BESS	Field camps, processing facilities, remote flow stations	Reduces genset fuel use; provides daytime power + load shifting	Requires high CAPEX and land footprint	Small-to-medium (1–20 MW)
Wind Energy	Offshore platforms, coastal operations	Provides clean offshore power; hybrid with gas turbines	Variability in wind speed; requires subsea cable links	Medium-to-large (10–100 MW)
Green Hydrogen	Refineries, downstream processes	Zero-carbon fuel for heating and blending; long-term export potential	High cost of electrolysis; early stage deployment	Medium-to-large (>10 MW by 2030)

Renewable Energy Pathways in Nigeria’s Oil & Gas Sector: Current vs Future Potential

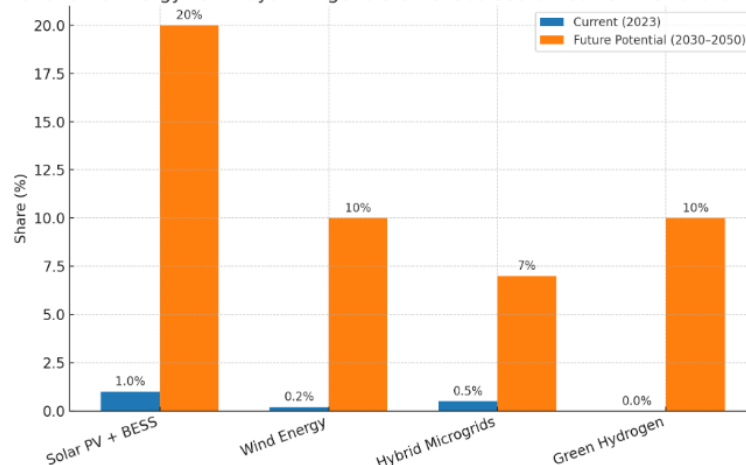


Figure 2: Current (2023) vs. Future Potential (2030–2050) renewable energy integration in Nigeria’s oil & gas sector, based on realistic national data and projections (REMP and IRENA).



CHALLENGES TO RENEWABLE ENERGY INTEGRATION

Despite its potential, integrating renewables into Nigeria's oil and gas sector faces significant barriers. These include:

- i. High Capital Costs: Solar microgrids and green hydrogen facilities require substantial investment (\$1-2 million/MW for solar, \$3-5 million/ton for hydrogen) (Adebayo *et al.*, 2024).
- ii. Limited Funding: Nigeria's budget constraints and reliance on oil revenue limit capital for renewable projects.
- iii. Infrastructure Limitations/Grid Instability: Nigeria's unreliable grid complicates integration of large-scale renewables (John *et al.*, 2025).
- iv. Logistical Challenges: Transporting renewable energy equipment to remote Niger Delta fields is costly and complex.
- v. Technical Expertise/Skill Gaps: Lack of trained personnel in renewable energy technologies hinders implementation (Shao *et al.*, 2025).
- vi. Maintenance Needs: Renewable systems require specialized maintenance, challenging in remote areas (Sobajo, 2024).
- vii. Inconsistent Policies: The PIA and Nigeria's Energy Transition Plan lack clear incentives for renewables in oil and gas (Ekechukwu & Eziefula, 2025).
- viii. Bureaucratic Delays: Licensing and approvals for renewable projects can take years.
- ix. Community Resistance: Local communities may oppose projects due to land use concerns or lack of direct benefits (Adebayo *et al.*, 2024).
- x. Environmental Risks: Improper installation of renewable systems could lead to ecological damage in sensitive areas like the Niger Delta (Nkalo, 2025).

To overcome these challenges, a strategic framework for integrating renewable energy into Nigeria's oil and gas sector must be adopted. This study thus proposes:

- i. Pilot Projects: Deploying small-scale projects, such as 3MW solar microgrids, in Niger Delta fields could help in demonstrating feasibility. For example, a pilot at OML 29 could power drilling rigs, reducing costs and emissions (NUPRC, 2024). Similar hybrid solar-battery systems have been successfully deployed in offshore Norway and the Saudi Aramco Khurais field, where renewables support continuous oil production while reducing carbon intensity.
- ii. Public-Private Partnerships (PPPs): Funding can be obtained by collaborate with international firms (e.g., TotalEnergies, Shell) to finance renewable projects. As seen in Norway's Hywind Tampen project, where offshore wind powers oil platforms. This will also facilitate a technology transfer by leveraging on their global expertise to build local capacity (NUPRC, 2025).
- iii. Policy and Regulatory Support: Introduce tax breaks and subsidies for renewable energy adoption in oil and gas. Also, simplifying licensing processes to accelerate project deployment (Eli Jidere Bala, 2014). Lessons



can be drawn from Saudi Arabia's Vision 2030, which created a clear regulatory pathway for renewable integration in oil facilities.

- iv. Community Engagement: Investing in community infrastructure, such as schools, hospitals, etc., can serve as channels to gain social license and trust of the host communities. Local community workers can also be trained on renewable energy, thus reducing unrest (John et al., 2025).
- v. Environmental Safeguarding through Sustainable Design: Companies should prioritize eco-friendly materials and waste management in the deployment renewable energy installations (Ogunlana & Ezeoha, 2021). This approach align with international ESG frame work applied in offshore Norway and north sea.

CONCLUSION

Nigeria's oil and gas industry faces both a need and an opportunity to include renewable energy. Renewables and hybrid systems are practical because they lower greenhouse gas emissions, increase energy security for remote facilities, and lower operating costs. Careful integration strategically promotes job growth, economic diversification, and better community access to electricity. Regulatory alignment, finance innovations, technical capacity building, clear policies, and value-demonstrating staged pilots are all necessary to achieve these results. Nigeria can transform its hydrocarbon history into a foundation for a low-carbon, inclusive energy future if it has the appropriate government, investment, and industry leadership (Amulah, 2022).

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