

A Review of Nigeria's Energy Mix Utilisation and Management: Challenges and Prospects for Economic Growth

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ABSTRACT

Energy is a critical driver of economic growth and industrial development. Being endowed with vast energy resources, Nigeria faces persistent challenges in effectively managing and utilising its energy mix to stimulate economic progress. This paper examines Nigeria's current energy mix configuration, utilisation, and management; the hurdles hindering optimal utilisation; and the prospects for sustainable economic growth through efficient energy management, using a descriptive and investigative approach. This paper explores various energy policy directions and strategies required to drive energy efficiency to accessibility, affordability, availability and sustainability. The implication of this study is influenced by and geared towards re-engineering several energy mix policies and initiatives, such as the National Renewable Energy and Energy Efficiency Policy (NREEEP), Nigeria Energy Transition Plan (ETP), National Energy Policy (NEP), National Energy Master Plan (NEMP), and the most recent, Presidential Initiative on Compressed Natural Gas (Pi-CNG). It is observed that these policies and initiatives are aimed at contributing immensely to an effective energy mix and diversification, promoting economic growth and prosperity through accelerated employment generation, improving revenue earnings, reducing the carbon footprint, and advancing sustainable development goals. Findings have shown that poor implementation of these policies and initiatives, often due to a lack of political will, conflicts of interest within the political class, and elitist influence, has stalled continued adherence to the implementation processes of these aforementioned policies. However, it ought to be encouraged that policy initiatives and strategies are not good enough unless they are implemented and monitored to endure over time. So that potential prospects in energy diversification and management will be accomplished with adequate collaboration among all stakeholders to harness the opportunities of energy mix utilisation for cost-effective and environmentally sustainable solutions. This review presents a comprehensive overview of current energy mix management, current practices in the petroleum industry, and opportunities to be leveraged in other sectors. A detailed account of policy directions and initiatives is presented, with associated challenges and ways they can be utilised for opportunities and prospects.

Keywords: mix energy, management, utilisation, challenges, prospects, economic

INTRODUCTION

Energy, through its sources, plays a fundamental role in any nation's industrialisation, commerce, and overall socio-economic development. Nigeria, the acclaimed largest economy in Africa, has diverse energy resources, which it classifies as fossil and non-fossil sources, including crude oil, natural gas, coal, hydro, solar, biomass, and wind. However, inefficient utilisation and mismanagement of these resources have led to energy deficits, hampering productivity and economic expansion. While energy is believed to be the primary driving force that activates economic activities of any nation, priority is always given to utilising it in a compositional perspective to leverage its sustainability and regular availability for any nation. Once your energy-mix capacity, utilisation, and management are optimal, increasing access to energy will be the cornerstone for elevating human and material standards, thereby guaranteeing economic prosperity [1].

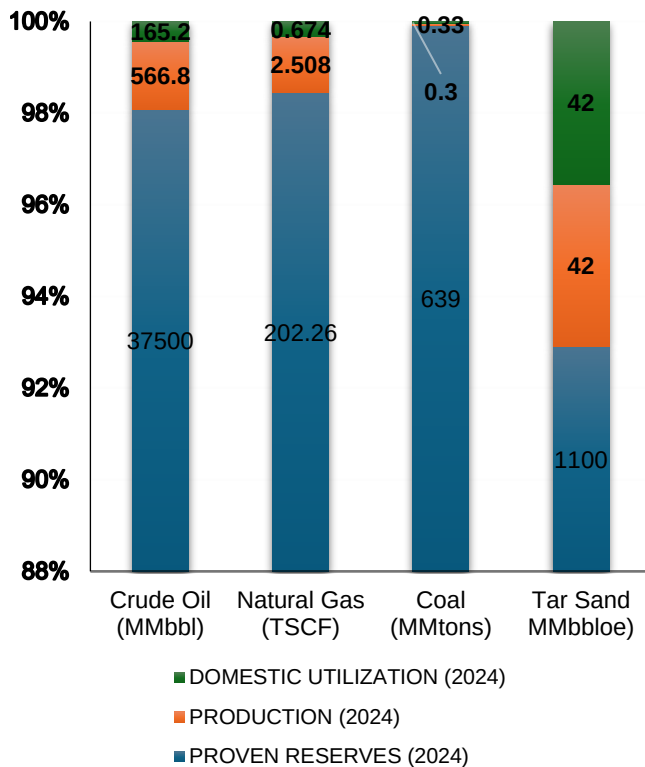


Fig. 1: Nigeria's Fossil Fuel Proven Reserve, Production and Domestic Utilisation

In the context of world economics, the quest for economic power between developed and developing or underdeveloped economies is justified against the backdrop of harnessing energy-dominant capabilities. The two largest economies of the world (the USA and China) are identified by the dominating factors associated with the utilisation, economics, and management of energy resources. At the same time, the quest for economic growth is also a clear justification for the rapidly growing world population, mostly due to urbanisation, technological advancement, and innovation [3]. The world has always been energy-thirsty and will remain so for the foreseeable future. This is why proper and effective combination (mix), utilisation, and management of energy sources will remain a damning factor for economies rallying growth and development in the current century. Hence, the need to maximise the use of affordable, available, and sustainable energy sources has become a front-and-centre challenge for researchers in the energy field to quench the thirst for energy caused by persistent supply shortages [2]. Therefore, to avert this catastrophic supply shrinkage, efforts are geared toward exploring energy-efficient strategies that use available resources for conversion, and deploying combinations of energy sources for the same consuming public is considered the ultimate solution, resulting in the use of the phrase “energy-mix”.

According to the Onoir Africa Energy Report (2025), among the 54 countries in Africa, Morocco, South Africa, Egypt, Algeria, Ghana, Botswana, and Malawi are among the top 10 countries with above-average policy implementation in energy mix management and utilisation. Sub-Saharan Africa is the most affected by energy deficits, due to poor implementation and management of its energy mix advantages [1]. Africa is blessed with invaluable energy resources to achieve a perfect energy mix, utilisation, and management solutions. With one of the highest levels of sunshine, solar energy harvest is a force to be reckoned with, while wind energy is being under-exploited, and geothermal energy is never in the news. Africa has to overcome challenges such as infrastructure deficits, funding gaps, and inadequate regulatory frameworks. Morocco has set itself the ambitious target of achieving a 52% share of renewable energy in its energy mix by 2030, with a strong emphasis on solar and wind power. To support this transition, the country has implemented an incentive-based legislative framework that attracts international investors and partners for green infrastructure projects. South Africa, despite its dependence on coal, is developing significant wind and solar projects to meet a 12% renewable energy target by 2030, with substantial incentives for manufacturers and end users [2].

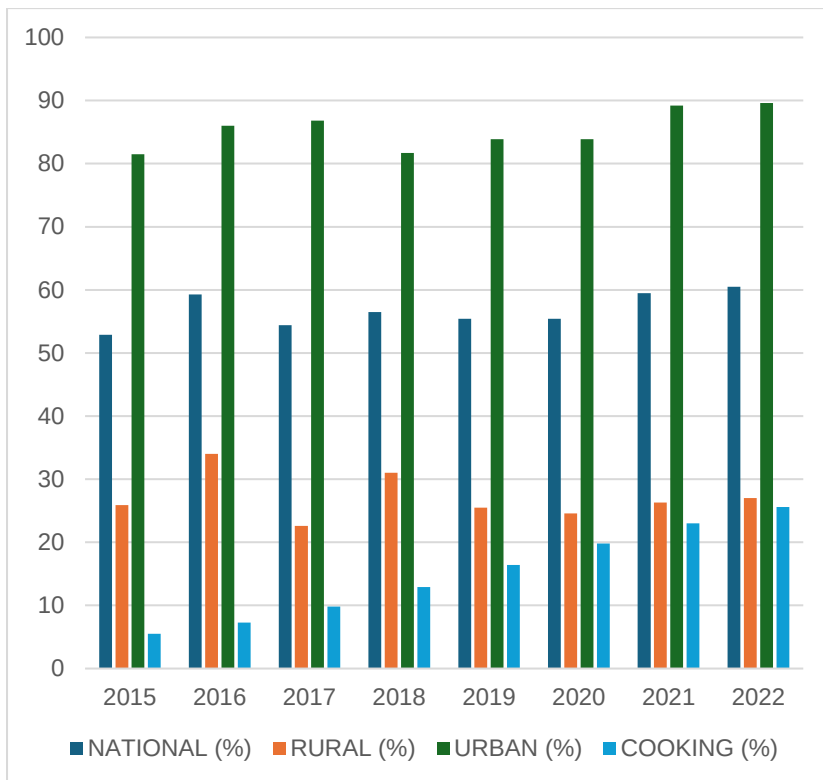


Fig 2: Profile of energy access in Nigeria (Source: Africa Energy Portal)

Energy is a vital ingredient of economic progress, and for a country like Nigeria to develop its economy, it needs to channel its economic growth policy through its endowed energy resources, such as Oil, gas, coal, solar, hydro, geothermal, biomass, and other available renewable energy sources [4]. The resultant effect of these energy sources on end users is usually in the form of electricity, fuels, and process heat, which are utilised as drivers of the socio-economic privileges of the people (end users). Achieving energy stability is possible through smart distribution, storage, and grid management. Countries with stable energy sources have invested in modern infrastructure to curtail limitations associated with energy losses [7].

The nature and extent of energy demand and utilisation in a national economy largely indicate its level of economic growth. For a productive economy and rapid, secure economic advancement, the country must pay maximum attention to synergistic development, utilisation, and effective management of its energy resources, and to the secure supply of its energy needs. It must disassociate itself from the weak legislative framework and policy disconnect [5]. To do this, the country needs to put in place a coordinated and coherent energy implementation policy (since the policies are already in place) to serve as a blueprint for the sustainable development, supply and utilisation of the energy resources within the economy [4]. Like many other African nations, Nigeria is endowed with several energy sources, including oil, gas, coal, tar sands, biomass, hydropower, wind, solar, and tidal energy. These energy sources, when diversified, can achieve an efficient energy mix for the country. Since countries that rely on a mix of fossil and renewables, such as hydro, wind, natural gas, and other sources, are better equipped to prevent disruptions and can handle transmission shortages and maintain a consistent supply [7]

Overview of Nigeria's Policies

With proper energy mix utilisation and management, it can effectively resolve the energy deficit challenges the country is currently facing. A stable power grid requires government policies that encourage private-sector investment and ensure regular infrastructure maintenance [5]. In terms of policies, Nigeria has several policies and initiatives aimed at implementing a diverse energy mix to improve energy access and sustainability. Below are a few of the enumerated policies and initiatives:

National Renewable Energy and Energy Efficiency Policy (NREEEP): This policy focuses on integrating renewable energy sources like solar, wind, biomass, and hydropower into Nigeria's energy mix. It also promotes energy efficiency across various sectors, including residential, industrial, and transport.

National Energy Policy (NEP) & National Energy Master Plan (NEMP): Approved in 2022, these documents provide a framework for optimising Nigeria's energy resources, including fossil fuels and renewables, to enhance energy security and economic growth. These NEMP documents provide a comprehensive policy direction for Nigeria's energy sector, ensuring the optimal utilisation of energy resources for sustainable development. At the same time, NEP serve as a roadmap for the implementation of NEMP, translating its strategies into actionable programs, activities, and projects.

Nigeria Energy Transition Plan (ETP): This initiative is a comprehensive strategy designed to tackle the dual crises of energy poverty and climate change and deliver SDG7 by 2030 and net-zero by 2060. The plan focuses on reducing emissions in five key sectors: Power, Residential Buildings, Industry, Transport and Oil & Gas. The plan requires ~\$410 billion in incremental funding between 2021 and 2060, averaging \$10 billion per annum over the period. The plan was designed in partnership with the UK Energy Transition Council, Sustainable Energy for All (SEforALL) and McKinsey.

Nigeria Gas Master Plan (NGMP): This strategic framework is designed to transform Nigeria's gas sector into a market-driven industry. It was introduced to maximise the country's vast natural gas resources, drive economic growth, and enhance energy security. The NGMP is periodically updated to adapt to changing market conditions and align with Nigeria's long-term energy goals [24].

The National Integrated Electricity Policy (NIEP) is a comprehensive framework designed to transform Nigeria's electricity sector. The Federal Government approved it in May 2025 and aims to enhance energy security, improve governance, and drive investment across the electricity value chain. Introduces a three-tier electricity market, such as the National Wholesale Electricity Market (NWEM), State Electricity Markets (SEMs), and Off-grid Markets and sets ambitious targets for nationwide electricity access by 2030 [18]. It focuses on improving generation capacity, reducing reliance on diesel, and upgrading transmission infrastructure. It encourages the integration of renewable energy sources and promotes energy efficiency. It aligns with the Electricity Act 2023 and replaces the outdated National Electric Power Policy of 2001. When properly and meticulously implemented, it is expected to reshape Nigeria's power sector and foster a more reliable and sustainable electricity supply [9].

Presidential Initiative on Compressed Natural Gas (Pi-CNG): This initiative aims to provide Nigerians with a cheaper, cleaner, and more sustainable alternative to petrol, aka. PMS. It was introduced as part of the government's response to the fuel subsidy removal, helping to reduce transportation costs and improve the standard of living by promoting the use of domestically produced natural gas while expanding CNG infrastructure, such as refuelling stations and conversion centres, reducing reliance on petrol and minimising environmental pollution. The initiative is expected to boost Nigeria's energy transition and increase the scope of the national energy mix strategy [30]. These policies aim to diversify Nigeria's energy sources through an improved energy mix strategy, enhance sustainability, and drive economic progress. The policies enumerated above are geared towards developing energy generation, especially renewable energy sources such as hydro, solar, wind, geothermal, biomass, tidal, and wave energy. Every effort must be made to utilise these vast energy resources available to the country.

Overview of Nigeria's Energy Mix Composition

Nigeria is a country richly blessed with virtually all kinds of energy resources, like many other African nations. It is generally considered one of the most developed developing nations in Africa, with highly endowed human and natural resources. However, increasing access to energy products, especially electricity and fuel, has proven to be not only an ongoing challenge but also a pressing issue for the Nigerian population and the international community at large. Economic growth is a prerequisite for any nation to move from a third-world nation to a developed country. The greater the energy resource composition and

Key

- Concentrating Solar Power
- Hydropower
- Wind
- Natural gas
- Coal

Crude Oil & Petroleum Products:

FRACTIONAL DISTILLATION CRUDE OIL

The diagram illustrates the fractional distillation process of crude oil. On the left, a tank labeled 'CRUDE OIL' feeds into a 'FURNACE' represented by a stylized orange and red structure with four small burner icons at its base. A pipe leads from the furnace to a tall, vertical distillation column. The column has several horizontal outlets at different heights, each labeled with a petroleum product and its corresponding boiling point range. To the right of the column, various icons represent the uses of these products: petroleum gas (gas cylinders), gasoline (a car), naphtha (cleaning bottles), paraffin (an airplane), diesel (a truck), fuel oil (a power plant), lubricating oil (a car engine), and bitumen (road tar). The products are listed from top to bottom: PETROLEUM GAS (< 25 °C), GASOLINE (< 25-60 °C), NAPHTHA (< 60-180 °C), PARAFFIN (< 180-220 °C), DIESEL (< 220-250 °C), FUEL OIL (< 250-300 °C), LUBRICATING OIL (< 300-350 °C), and BITUMEN (< 350 °C).

Product	Boiling Point Range (°C)
PETROLEUM GAS	< 25
GASOLINE	< 25-60
NAPHTHA	< 60-180
PARAFFIN	< 180-220
DIESEL	< 220-250
FUEL OIL	< 250-300
LUBRICATING OIL	< 300-350
BITUMEN	< 350

www.rsisinternational.org

Natural Gas

As of February 2025, according to IEA data, Nigeria holds the second-largest oil reserves in Africa, at 37.28 Bbbl (18.1%), behind Libya, which holds 48.7 Bbbl (20.5%). In terms of gas reserves, Nigeria still holds the largest gas reserves in Africa, with 210.4 Tscf, accounting for roughly 3% of global proven reserves, making Nigeria the 9th-largest globally, ahead of Algeria, which holds 158.1 Tscf. However, the gas sector remains largely underdeveloped, with a production-to-reserve ratio of approximately 1%.

It is, however, pertinent that Nigeria currently focuses on domestic utilisation of its natural gas resources to harness its productivity potential by adopting its numerous value-added propositions for the domestic gas sector, thereby providing the much-needed economic impetus for the country. According to data provided by PwC, harnessing Nigeria's proven gas reserves can generate Gross Value Added (GVA) returns of US\$18.3 billion annually to the domestic economy. This is to foster domestic gas utilisation, supporting 6.5 million Full-Time Equivalent (FTE) jobs in the local economy.

In terms of gas production in 2024, Nigeria produced a total of 2.508 (Tcf) of natural gas comprising 1.44 Tcf of associated gas and 1.06 trillion cubic feet (Tcf) of non-associated gas representing an increase in 2.491 Tcf from 2023, generating approximately N8.6tn from natural gas production in 2024, this is Data from the Nigerian Upstream Petroleum Regulatory Commission which also indicated that the country produced 2.5 trillion cubic feet (Tcf) of gas during the year under review. Associated gas is a form of natural gas found with deposits of petroleum, either dissolved in the oil or as a free 'gas cap' above the oil in the reservoir. Similarly, 1.06 Tcf of non-associated gas was produced during the period under review. Non-associated natural gas is a type of natural gas that is produced in gas fields that do not contain crude oil.

However, out of the 2.5TCF of gas produced in 2024, 2.31 trillion cubic feet (Tcf) was utilised, while 192.89 billion standard cubic feet of gas was flared. Nigeria holds more non-associated gas in its reserves than associated gas, yet the latter accounts for more than half of the total gas produced annually. Associated gas accounted for about two-thirds (66%) of the total gas produced in the eighteen years, with non-associated gas making up the balance of 34%. According to Price Water Coopers (PwC) 2024 report on Nigeria's gas value chain evaluation.

Nigeria has every opportunity to diversify the natural gas value chain and benefit from tremendous financial and economic gains, as countries like Qatar and Russia have. However, incoherent political strategy has, most of the time, led to a weak policy framework and implementation for natural gas resource management in Nigeria. This has also led to weak implementation of natural gas policies and action plans, including relatively low gas flare penalties and insufficient domestic gas utilisation projects. Until recently, Compressed Natural Gas (CNG) utilisation in Nigeria has been implemented only in Benin City for cars, the Nestle Shagamu factory, and Power Gas Africa [14]. The current administration's effort to relaunch the Presidential initiative for the Compressed Natural Gas (Pi-CNG) is to serve as a buffer for the removal of the fuel subsidy in 2023.

In Nigeria, natural gas is primarily used for power generation, as feedstock for gas-based industries, and as fuel for vehicles. While Nigeria has significant natural gas reserves and production, a large portion is flared or reinjected, indicating underutilization. Efforts are underway to improve domestic gas utilisation, including expanding gas-based industries and developing infrastructure for domestic and export markets. To summarise these illustrations, below is a table showing Nigeria's fossil fuel assets in terms of reserves, production and domestic utilisation.

A Decade of Gas Initiative

The Nigeria Decade of Gas Initiative, launched in July 2021, represents a robust effort by the government and private sector to leverage the country's abundant natural gas resources for economic development and energy transition. During the decade, Nigeria is committed to increasing production and consumption of natural gas by over fifty per cent (50%). This is expected to be achieved through a series of policy reforms,

gas supply project maturation, gas infrastructure expansion, capacity building and robust investment attraction strategies [5].

The future of natural gas in Nigeria as an energy source is potentially strong across many sectors of the economy that require gas for utilisation purposes. This is very important because natural gas plays a crucial role in the growth and development of the economy's industrial and commercial sectors, given that it has a low carbon footprint during its use, thereby helping safeguard the natural ecosystem [4].

In Nigeria, there is an urgent need to drive the nation toward a greener, safer environment amid economic advancement; hence, there is an urgent need to replace high-carbon-emission fossil fuels, such as oil and coal, with low-carbon energy sources to meet acceptable industrial emission standards. This can be achieved in an industrial sector that is forward-looking during economic advancement. For example, the rise in the petrochemical, textile, and pharmaceutical industries that utilise natural gas as a feedstock further emphasises the growing demand for natural gas in the industrial sector [4].

In the power sector, for example, natural gas, with other renewable energy sources such as wind, hydro, solar, etc, are earnestly being introduced to replace the high carbon impact fossil fuels such as coal and oil in the energy mix across areas seen to be suitable for their introduction as such some oil and coal based power generating plants are gradually being replaced with gas-powered and other renewable energy power generation units such as from solar and wind power units [5].

In the transportation sector, there are fewer natural-gas-powered vehicles in Nigeria than in other nations with similar demographics, such as China, Brazil, and Malaysia. However, the new Presidential initiative on Compressed Natural Gas (Pi-CNG) is being vigorously pursued with greater investment, momentum, and encouragement for both corporate, commercial, and individual sectors. In 2024, based on PwC reports, Nigeria is estimated to have about 5,000 fuel-powered vehicles (PMS and Diesel) converted to CNG over the past 10 years. Official statistics indicate that Nigeria could save N10 trillion annually if all vehicles in Lagos, Abuja, and Port Harcourt were converted to use CNG instead of conventional petroleum liquid fuels (PMS and AGO) [5]. The government has taken bold steps to incentivise the initiative and increase awareness of its efficiency and affordability compared to traditional fuels such as diesel and premium motor spirit; hence, corporate organisations are keying in droves to maximise their benefits in terms of cost and efficiency. This has further encouraged the government to expand its current investment in natural gas infrastructure, such as the OB3 gas project, the NLNG Train 7 and the Abuja-Kaduna-Kano gas pipeline projects, with a sharp increase currently being witnessed in the gas exploration and production activities, which are increasing natural gas supplies to the domestic market. Other factors driving the shift to natural gas include the volatility of the global crude oil supply due to frequent geopolitical tensions, policy somersaults by major oil-importing countries driven by emissions control measures, and an increased emphasis on renewable energy sources.

Hydropower

Nigeria has an estimated total hydropower potential of 14,120 MW, with only 2,858 MW developed so far [13]. Again, with vast untapped hydropower resources, particularly along major rivers such as the Niger, Benue, Kaduna, and Cross River. Efforts to expand hydropower capacity are ongoing, with discussions aimed at improving infrastructure and attracting private investment to develop the country's hydropower potential further. Renewable but affected by seasonal variations. Nigeria has significant hydro energy potential across various states, particularly those with major rivers and water bodies. Some states identified with small hydropower (SHP) potential include Borno, Niger, Edo, Anambra, Jigawa, and Plateau. For instance, Plateau State has existing small-scale hydropower stations, such as the 2MW station at Kwall Falls on the N'Gell River (Kaduna River) and an 8MW station at Kura Falls. While detailed water volume data for each state isn't readily available, these states have substantial water resources suitable for hydropower development [11].

Table. 1: Status of hydro energy to power projects in Nigeria

HYDRO ENERGY TO POWER PROJECT IN NIGERIA				
Source: http://globalsolaratlas.info				
STATE	LOCATION	HYDRO ENERGY CAPACITY (CBFT)	HYDRO POWER CAPACITY (MW)	STATUS
NIGER	KAINJI DAM	130.7	980	Completed,1969
NIGER	JEBBA DAM	162.5	578.4	Completed, 1984
NIGER	SHIRORO DAM	120.1	600	Completed, 1990
NIGER	ZUNGERU DAM	120.1	700	Completed, 2022
BENUE	MAKURDI	169.5	1650	2033
KOGI	LOKOJA DAM	113	750	2033
TARABA	MAMBILA DAM	137.7	3050	2027
		TOTAL (AT 2033)	8308.4	

(Source: <http://globalsolaratlas.info>)

Nigeria has attracted about \$8 billion in energy investments, including deepwater and gas projects, within the past year [8]. This signals strong investor confidence in the country's energy sector. Nigeria continues to attract global interest in its renewable energy landscape due to market reforms and investment incentives. Studies highlight the potential of small hydropower (SHP) projects across Nigeria, emphasising their role in rural electrification and sustainable energy [21].

According to the Energy Commission of Nigeria (ECN, 2021), Nigeria has over 278 small hydropower sites with an estimated capacity of about 734 MW, suitable for powering rural and off-grid communities. Nigeria is actively working on renewable energy projects, including hydropower, to diversify its energy mix and reduce reliance on fossil fuels.

The Federal Ministry of Power (FMP, 2022) confirms that Nigeria is expanding its renewable energy portfolio under the Renewable Energy Master Plan and the Nigeria Energy Transition Plan. The Nigerian government is implementing policies to attract investors and improve infrastructure for hydropower development. Through instruments such as the Electrification Financing Initiative (ElectriFI) and support from the World Bank's Nigeria Electrification Project, the country is enhancing investor confidence and expanding energy access [18]. These insights indicate a growing focus on hydropower and renewable energy in Nigeria.

Solar & Wind Energy Resources

As the world intensifies its search for sustainable energy solutions, solar and wind power have emerged as front-runners in the transition to a low-carbon future [15]. In many developing economies, including parts of Nigeria, interest in these renewable resources is at an all-time high [16]. Policymakers, investors, and other stakeholders are increasingly recognising the potential of solar photovoltaic (PV) systems and onshore/offshore wind farms to diversify energy sources, reduce greenhouse gas emissions, and create green jobs [17].

Despite the surge in enthusiasm, solar and wind energy remain in their early stages of development across the country. Installed capacities are growing from a low base but often face challenges such as limited grid infrastructure, inadequate financing mechanisms, and regulatory uncertainties. Nigeria's solar energy utilisation accounts for less than 2% of total power generation, while wind contributes even less, highlighting the untapped potential.

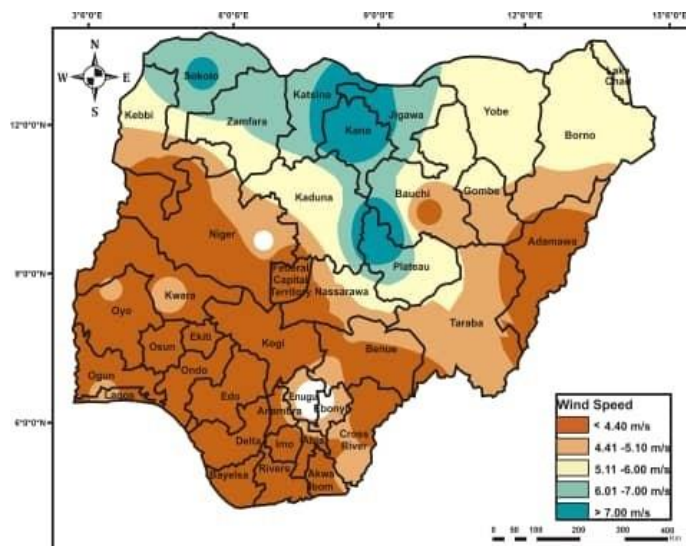


Fig. 5: Maps showing Nigeria's wind energy output by states (IRENA, 2023)

With declining technology costs, solar panels have fallen by over 80% in price over the past decade, and wind turbines have become increasingly cost-effective. This has sparked optimism that renewable energy can leapfrog traditional fossil energies. Yet large-scale deployment still depends on addressing issues such as grid integration, energy storage, and local technical capacity. To accelerate the maturity of solar and wind energy markets, stakeholders must collaborate on innovative financing, supportive policy frameworks, and skills development. Public-private partnerships can play a crucial role in unlocking investment and building resilient supply chains. Moreover, decentralised solutions like solar mini-grids and small-scale wind systems could offer immediate benefits to rural and underserved communities. Ultimately, while solar and wind energy are no longer niche technologies, realising their full potential will require sustained commitment and strategic planning to move from promising beginnings to widespread, transformative adoption. The growing interest in solar and wind energy at this critical juncture of energy starvation in Nigeria is a concern that requires clear and in-depth reflection from the policymakers, relevant stakeholders and the general public, especially as the country walks through various policy frameworks, energy generation and distribution initiatives, energy promotion programs and investment strategies.

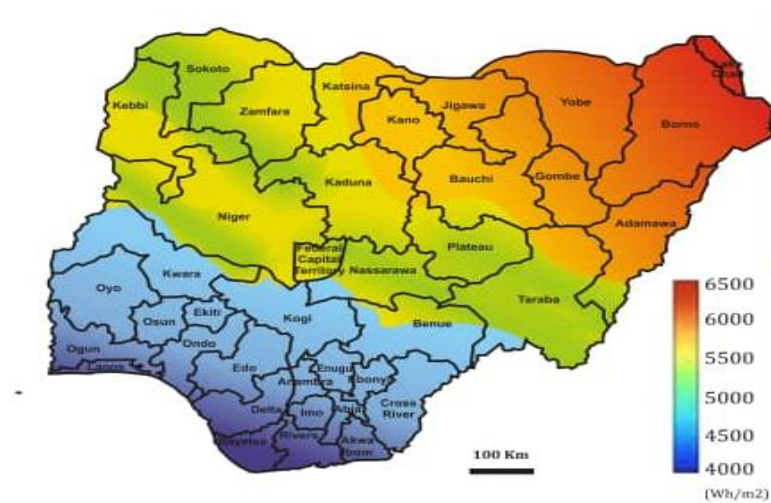


Fig. 6: Maps showing Nigeria's solar energy output (IRENA, 2023)

Like many other African nations, Nigeria is an easy-harvest zone with abundant solar energy and, to a point, above-average wind energy resources, which offer enormous potential for diversifying its energy mix, improving its energy security, and reducing dependence on current fossil energy resources. Initiatives such as the government's Solar Power Naija program through the Rural Electrification Agency (REA) aimed to expand off-grid solar energy access to over twenty-five (25) million underserved and unserved energy consumers. The initiative aimed to encourage policymakers and investors alike to promote the country's energy mix capabilities.

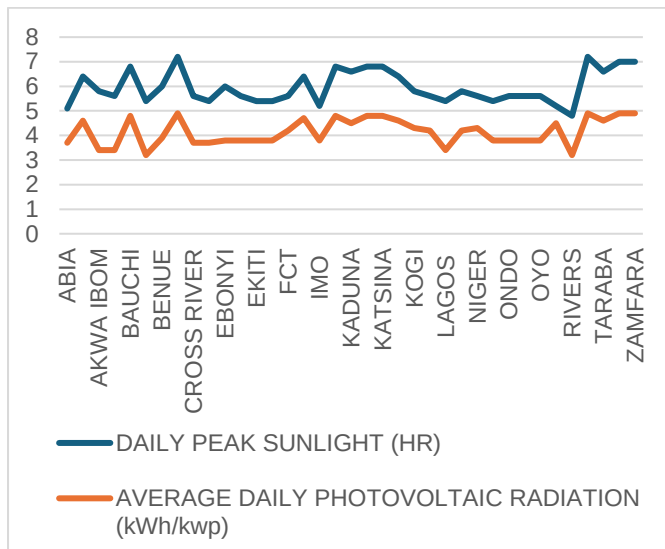


Fig 7: Mean daily solar energy density for Nigerian states (Source: <http://globalsolaratlas.info>)

The promotion of wind energy applications in Nigeria is at a standstill and is just beginning to gain traction among energy stakeholders. Various feasibility studies, as shown in Figure 4, were carried out to assess its credibility across different parts of the country, especially the northern axis. Yet, the development of these energy resources at utility scale is still in its early stages, with very little impetus, and a below-expected statistical evaluation of their contribution to current national energy utilisation can be established.

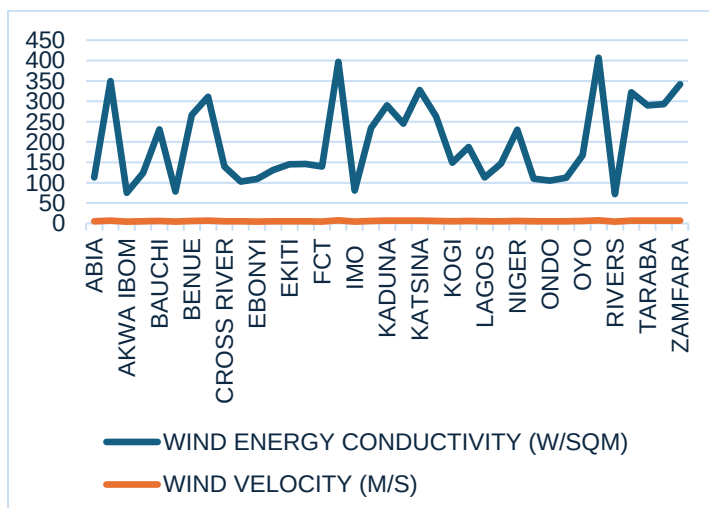


Fig. 8: Mean Power Density at Height 100m by Nigerian States (Data for 10% windiest areas)

The momentum in solar and wind energy remains at the project development stage in Nigeria. Although Solar contributes less than 1% of national energy utilisation, wind energy utilisation is virtually non-existent. This slow uptake is largely due to challenges associated with inadequate grid infrastructure, limited access to affordable long-term financing, regulatory bottlenecks, and gaps in technical expertise [24].

What is encouraging is that the cost of solar and wind technologies has been sliding dramatically in recent years, making them increasingly competitive with traditional energy sources. However, realising their potential requires deliberate, coordinated action, in which policymakers and other relevant stakeholders can act promptly. Nigeria's solar and wind resources are among the best in Africa. By addressing key barriers now, policymakers can shift solar and wind energy from promising opportunities to pillars of a sustainable, inclusive, and resilient energy future for all Nigerians.

Coal, Biomass and Waste-to-Energy Resources

Nigeria possesses abundant coal and biomass energy resources, offering viable alternatives to fossil fuels and supporting the country's ambition to diversify its energy mix. These resources, if sustainably harnessed with the right technology that can limit greenhouse gas emissions and advance sustainable development goals, can play a key role in reducing energy poverty and stimulating economic growth.

Coal deposits in Nigeria are found mainly in Enugu, Kogi, Gombe, and Benue states. Nigerian coal is sub-bituminous and well-suited for thermal applications. According to the Nigerian Geological Survey Agency (NGSA) 2020 annual report, Nigeria has an estimated 2.8 billion metric tonnes of coal reserves, with proven reserves of about 600 million tonnes [19].

While coal use declined after the 1960s due to the dominance of oil, interest is reviving in sectors such as cement production and steel processing. Companies such as Dangote Cement and Lafarge Africa have integrated coal into their energy mix to reduce production costs [15].

Biomass remains the most widely consumed renewable energy source in Nigeria, accounting for over 80% of household energy consumption, particularly in rural areas. Sources include firewood, charcoal, crop residues, animal waste, and urban solid waste. Traditional methods—such as open firewood cooking—dominate, contributing to deforestation and indoor air pollution. However, the Nigerian government and development partners are promoting modern biomass technologies. These include improved cookstoves, biogas digesters for domestic gas supply, and biomass briquetting for small-scale industries [23].

In northern Nigeria, agricultural residues like groundnut shells and maize stalks are being converted into pellets and briquettes. Additionally, waste-to-energy projects in Lagos and Ibadan are being piloted using municipal waste to generate electricity. Hence, to fully harness the coal and biomass energy potential, Nigeria must improve regulatory frameworks, attract private investments, and support clean energy technologies. Modernising the biomass sector and ensuring cleaner coal technologies can boost energy access and reduce environmental impacts [23].

Sector-wide Energy Demand Analysis

Four key sectors shape Nigeria's energy demand. The power sector, which faces rising demand due to population growth and industrialisation, yet supply remains constrained by limited generation and transmission capacity [15]. The transportation sector is dominated by petroleum products, accounting for over 55% of national fuel consumption, with efforts underway to introduce compressed natural gas (CNG) and electric mobility [20]. The residential sector consumes a significant amount of biomass and electricity, primarily for cooking and lighting, which contributes to deforestation and energy poverty [19].

Meanwhile, the industrial sector relies heavily on natural gas, diesel, and captive power generation, which drive up production costs but also offer opportunities to integrate renewable energy [35]. Addressing inefficiencies in these sectors is critical to Nigeria's sustainable energy future, considering the recently released list encouraging sector-wide energy demand by the International Energy Agency (IEA).

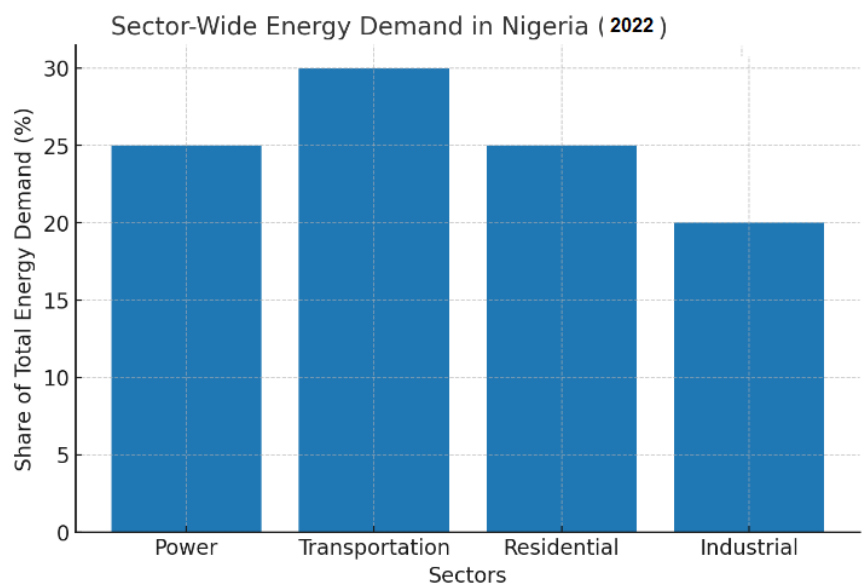


Fig 9: Comparison of energy demand across Nigeria's major sectors (IEA, 2022)

Energy Use Per Capita

Nigeria's Energy use per capita

This comprises all primary energy sources used before being transformed into other end-use fuels by an individual in a given period, typically yearly, within a particular geographical entity or country. In Nigeria, energy use per capita encompasses all energy sources, from domestic production to imports. For easy comparison, the energy is expressed in kilograms of oil equivalent. It is mathematically expressed as

Energy use per capita = (Local energy production) + (energy imports + stock changes) – (energy exports + fuels supplied for international mobility such as ships and airlines).

Table 2: Nigeria's Energy Use Per Capita

Nigeria	Energy use per capita
Latest value	333.06
Year	2022
Measure	kilograms of oil equivalent (kg oe)
Data availability	1971 - 2022
Average	427.67
Min - Max	256.92 - 685.14
Source	The World Bank

Challenges in Energy Mix Management

The combined effect of underinvestment and low technological innovation hampers the country's ability to diversify its energy mix. Gas continues to dominate electricity generation, while renewable sources contribute less than 10% of the energy mix. This imbalance undermines energy security, environmental goals, and efforts to meet international climate commitments, including the Paris Agreement and Nigeria's own Energy Transition Plan. The following challenges will be thoroughly discussed, considering their importance to the topic of discourse:

Infrastructural Deficiencies

Several challenges hinder Nigeria's ability to harness its energy resources effectively, including the

declining cost of renewable energy technology: solar accessories have decreased in price by over 80% in the past decade, and wind turbines have become increasingly cost-effective. This has sparked optimism that renewable energy can leapfrog traditional fossil energies. Yet large-scale deployment still depends on addressing issues such as grid integration, energy storage, and local technical capacity, including limited transmission networks and ageing facilities.

The growing interest in renewable energy at this critical juncture of energy starvation in Nigeria is a concern that requires clear and in-depth reflection from policymakers, relevant stakeholders, and the general public, especially as the country navigates various policy frameworks, energy generation and distribution initiatives, energy promotion programs, and investment strategies. Like many other African nations, Nigeria is an easy-harvest zone with abundant energy resources and, to a point, above-average energy resources, offering enormous potential for diversifying the energy mix to improve energy security and reduce over-dependency on current fossil energy resources. Initiatives such as the government's Solar Power Naija program through the Rural Electrification Agency (REA) aimed to expand off-grid solar energy access to over twenty-five (25) million underserved and unserved energy consumers. The initiative aimed to encourage policymakers and investors alike to promote the country's energy mix capabilities [18].

Policy and Regulatory Frameworks

Despite abundant solar irradiance, Nigeria's renewable penetration is constrained by high installation costs, limited technical expertise, heavy reliance on imports, policy inconsistency, and weak grid infrastructure. To address these, regulatory reforms such as the Electricity Act 2023 and incentives under the Renewables Master Plan and the COP26-aligned Energy Transition Plan (aiming for 30 per cent renewables by 2030) are being introduced [24].

Nigeria's solar and wind resources offer immense opportunities for driving its energy transition. To fully realise this potential, concerted efforts are needed: scaling up utility-scale projects, expanding decentralised systems, strengthening policy incentives, improving access to financing, building technical capacity, and reinforcing grid infrastructure. These steps are essential to sustainably meet rising electricity demand and achieve climate and development goals.

Energy Security Concerns

One of the major energy security concerns in Nigeria stems from its heavy reliance on fossil fuels, particularly crude oil and natural gas. Over 80% of the country's electricity generation is gas-powered. This narrow energy base makes Nigeria vulnerable to global oil price shocks, gas supply disruptions, pipeline vandalism, and sabotage in the Niger Delta region. Any disruption to fossil fuel infrastructure directly affects power availability and economic stability.

Nigeria has significant renewable energy potential, including solar irradiation exceeding 5.5 kWh/m²/day and numerous viable sites for wind and small hydropower. However, these sources remain largely untapped due to poor policy implementation, limited funding, a lack of technical expertise, and low private-sector participation. The delay in integrating renewables into the mainstream energy mix hinders diversification and weakens long-term energy security.

The national grid, plagued by inefficiency, instability, and high transmission losses, is a major bottleneck. Despite a generating capacity of over 13,000 MW, less than 5,000 MW is often evacuated or distributed due to infrastructural decay. Frequent grid collapses, poor maintenance, and limited rural electrification restrict energy access and resilience, making the energy sector highly susceptible to shocks. This is further exacerbated by inequitable access to modern energy services. According to the World Bank, around 90 million Nigerians lack access to electricity. High tariffs, rising fuel costs, and dependence on private generators disproportionately affect low-income households and SMEs. A secure energy future demands equitable distribution, yet this remains a decades-long challenge in Nigeria's energy governance.

A skewed energy mix, infrastructural weaknesses, policy lapses, and socio-economic disparities undermine Nigeria's energy security. Achieving a robust and resilient energy mix requires urgent reforms—accelerated investment in renewables, modernised infrastructure, clear policy direction, and inclusive energy planning. Only through such measures can Nigeria ensure long-term energy security that supports sustainable development and industrial growth.

Investment Deficits

Nigeria's energy landscape stands at a critical juncture, where the need for a diverse, secure, and sustainable energy mix has never been more urgent. With abundant energy resources ranging from oil and natural gas to solar, wind, hydro, and biomass. Nigeria possesses the raw potential to become a global energy powerhouse. However, persistent investment deficits and limited technological innovation have stalled progress in effectively managing its energy mix. These challenges undermine energy access, sustainability, and economic growth, placing the country's energy future at risk [27].

Despite the pressing need for diversification, Nigeria's energy sector suffers from chronic underinvestment. The country requires an estimated \$100 billion in energy infrastructure investment over the next decade, yet actual capital inflow remains significantly lower. Key factors contributing to this deficit include [28,30]:

- **Perceived Investment Risk:** Unstable policies, regulatory uncertainty, currency volatility, and security concerns, especially in the oil-producing Niger Delta, could deter foreign direct investment.
- **Government Funding Constraints:** Budgetary limitations hinder large-scale public investments in critical infrastructure such as power plants, transmission lines, and renewable energy facilities.
- **Low Private Sector Participation:** Inefficient public-private partnership (PPP) models, bureaucratic bottlenecks, and lack of financial incentives discourage private capital deployment.

This investment gap slows down energy infrastructure upgrades and delays renewable energy adoption, further deepening Nigeria's dependence on an outdated and inefficient fossil-fuel-based system.

Technological Limitations

The lack of technological innovation is another major challenge in managing Nigeria's energy mix. Technological limitations affect all aspects of the energy value chain:

- **Power Generation:** Most power plants in Nigeria operate below capacity due to ageing technologies and insufficient upgrades.
- **Renewable Energy Integration:** Nigeria lags in deploying modern technologies for solar grid integration, wind mapping, and battery storage systems. Advanced solutions like smart grids, AI-driven demand forecasting, and digital metering are either lacking or underutilised.
- **Local Content Development:** There is limited domestic capacity for research, development, and production of energy technologies, which leads to high dependence on foreign equipment and expertise.

Without focused innovation, Nigeria cannot transition effectively to cleaner, more efficient energy sources or compete in the global energy technology space.

Environmental Constraints

Nigeria's dependence on oil and gas, which together account for over 80% of its energy supply, has led to significant environmental degradation. Oil exploration and production activities in the Niger Delta have resulted in widespread land, air, and water pollution. Gas flaring, though reduced in recent years, continues to emit greenhouse gases and hazardous substances, contributing to climate change and health problems in surrounding communities. These impacts put pressure on the government to transition to cleaner energy sources while managing socio-economic dependence on fossil fuels [35].

Climate change poses a direct threat to energy infrastructure and planning in Nigeria. Rising temperatures, shifting rainfall patterns, and extreme weather events such as floods and droughts affect hydropower generation, disrupt energy logistics, and increase maintenance and resilience costs. For example, prolonged droughts have reduced water flow in major rivers such as the Niger and Benue, thereby impairing hydroelectric output at facilities such as the Kainji and Shiroro dams. Adapting infrastructure to withstand environmental shifts is both costly and urgent [36].

The proliferation of diesel and petrol generators used by millions of Nigerians to compensate for grid unreliability contributes significantly to air and noise pollution in urban areas. These small-scale, unregulated energy sources emit high levels of carbon monoxide, Sulphur dioxide, and particulate matter. Their environmental impact is often overlooked in official planning, yet they represent a critical constraint in managing a cleaner, healthier energy mix [36].

While Nigeria has established environmental laws and agencies such as the National Environmental Standards and Regulations Enforcement Agency (NESREA), enforcement remains weak. Limited capacity, corruption, and lack of coordination between federal and state institutions hinder compliance. As a result, energy projects often proceed without adequate environmental impact assessments (EIAs), undermining sustainability goals and exacerbating ecological damage [34]. Nigeria's path toward a sustainable and diversified energy mix is hindered by pressing environmental constraints from fossil fuel pollution and deforestation to weak regulatory enforcement and climate risks. Addressing these challenges requires integrated strategies: strengthening environmental governance, accelerating the adoption of clean energy technologies, investing in resilient infrastructure, and enhancing public awareness. A sustainable energy future for Nigeria must be about not only expanding supply but also protecting the environment on which the energy system and its people depend [37].

Inefficient Distribution

Nigeria relies heavily on a centralised transmission and distribution system that is outdated, fragile, and prone to frequent failures. The national grid, managed by the Transmission Company of Nigeria (TCN), often suffers from partial or total collapse due to poor maintenance and overloading. With over 13,000 MW of installed capacity, less than 5,000 MW is distributed on average. This disconnect between generation and end-use cripples energy availability across the country [18].

Despite Nigeria's abundant renewable energy potential, especially solar in the North and hydro in the central regions, these sources are minimally integrated into the national grid. Off-grid solar solutions, though growing, remain largely disconnected from broader energy planning. This lack of integration limits diversification of the energy mix and reinforces overdependence on gas-fired generation, which is subject to supply volatility [25].

Nigeria's distribution companies (DisCos) grapple with high technical and commercial losses estimated at over 40% in some areas. These losses result from outdated infrastructure, power theft, poor metering, and billing inefficiencies. As a result, even when power is generated, a significant portion is lost before it reaches consumers, further undermining the efficiency of energy delivery and planning [24].

Though Nigeria has formulated policies like the National Renewable Energy and Energy Efficiency Policy (NREEEP) and the Electricity Act 2023, poor implementation and weak inter-agency coordination hinder progress. Inconsistent regulations and inadequate incentives have led to underinvestment in distribution networks and limited private sector participation, thereby stalling improvements in energy allocation [24].

The inefficient distribution of energy sources remains a critical obstacle to effective energy mix management in Nigeria. Bridging the gap between energy potential and access requires massive investments in infrastructure, improved regulatory frameworks, and decentralised power systems, including mini-grids and off-grid solutions. Only by addressing these systemic issues can Nigeria achieve equitable, sustainable, and secure energy access for its population.

Prospects and way forward for economic growth through energy mix optimisation

The transformation of the energy sector will require strategic interventions that influence the utilisation and management of the energy mix for sustainable economic growth. These interventions should focus on:

- **Diversification of Energy Sources:** Expanding investment into renewables, particularly solar and wind, will reduce dependency on fossil fuels and enhance energy security.
- **Grid Expansion and Modernisation:** Strengthening Nigeria's transmission and distribution networks with the latest and most adaptable technology through upgrades will improve efficiency and minimise energy losses.
- **Private Sector Participation:** Encouraging continuous and sustainable investments in the entire energy sector value chain and providing incentives (tax breaks, guarantees, subsidies) to attract and encourage both domestic and international investors' participation.
- **Policy Reforms:** Implementing clear and stable energy policies and strengthening institutions such as the Rural Electrification Agency and Nigerian Electricity Regulatory Commission for transparent and sustainable oversight, such that innovations will be encouraged to foster the development of cleaner energy alternatives.
- **Technological Innovation:** Deployment of smart grid technology, artificial intelligence for demand forecasting, and improved storage solutions will bolster reliability and efficiency.
- **Energy Efficiency Initiatives:** Public education on efficient energy use and the adoption of energy-saving appliances will reduce waste and enhance sustainability.

By strategically addressing these areas, Nigeria can unlock economic growth potential, reduce dependence on volatile fossil fuel markets, and establish a robust energy sector.

CONCLUSION

Effective energy mix management is vital for Nigeria's economic growth. Overcoming infrastructural, regulatory, and technological challenges will enable the country to unlock the full potential of its energy resources. Strategic investments in renewable energy and innovative solutions can ensure energy security and industrial growth, positioning Nigeria as a global economic powerhouse. To accelerate the maturity of the country's energy markets, stakeholders must collaborate on innovative financing, supportive policy frameworks, and skills development. Public-private partnerships can play a crucial role in unlocking investment and building resilient supply chains. Moreover, decentralised, mixed-energy integration and solutions could offer immediate benefits to rural and underserved communities. Ultimately, while fossil energy technology is no longer a niche technology, developing its full potential in Nigeria will require sustained commitment and strategic planning to move from promising beginnings to widespread, transformative adoption. Nigerian policymakers can accelerate adoption by:

- **Strengthening policy frameworks:** Clear, stable regulations on renewable energy tariffs, licensing, and grid access will attract local and international investors.
- **Investing in grid modernisation:** Upgrading transmission and distribution networks is essential to integrate variable renewable sources and improve reliability.
- **Promoting local content and skills:** Developing local manufacturing and building technical capacity will reduce dependence on imports and create jobs.
- **Supporting decentralised solutions:** Mini-grids and solar home systems can quickly expand electricity access in rural and underserved communities, aligning with Nigeria's Electrification Strategy and promoting sustainable consumption practices.

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