ESL200: FUNDAMENTALS OF ENERGY ENGINEERING

TERM PAPER

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OVERVIEW

Nigeria, located in West Africa, is the most populous country on the African continent and although it holds significant geopolitical and economic importance in the region the actual economic condition of the country is very poor like its 163rd in Human Development Index Ranking. Bordered by Benin, Niger, Chad, and Cameroon, Nigeria's strategic location positions it as a key player in African affairs.

Nigeria boasts a diverse energy mix, with various sources contributing to its energy production. The country is renowned for its abundant reserves of oil and natural gas, which have historically been the primary drivers of its economy. Nigeria is a member of the Organization of the Petroleum Exporting Countries (OPEC) and is one of the top oil producers in Africa.

In addition to fossil fuels, Nigeria also harnesses the power of hydroelectricity from dams such as the Kainji and Jebba dams on the Niger River. These hydroelectric projects play a crucial role in providing electricity to the country's grid, particularly during periods of peak demand.

Although the country does not lack energy resource they are not able to use them much dues to many problems the main of them are lack of financial resources and technology to harness the resources in the country.

Indicator	2015
Population	181 million
Urban population	48% of total population
Land area (total)	923 000 square kilometres
Gross domestic product (GDP)	NGN 69 trillion (Nigerian naira)/USD 443 billion (2010)
Per capita GDP	NGN 381 215/USD 2 450 (2010) per capita
Access to electricity (% of population)	60% overall (urban: 86%; rural: 41%)
Access to clean cooking technologies (% of population)	18%

Overall, Nigeria's energy mix is characterized by a combination of traditional fossil fuels, hydroelectric power, and a growing emphasis on renewable energy development. This diversity reflects the country's commitment to meeting its energy needs while striving for environmental sustainability and energy security.

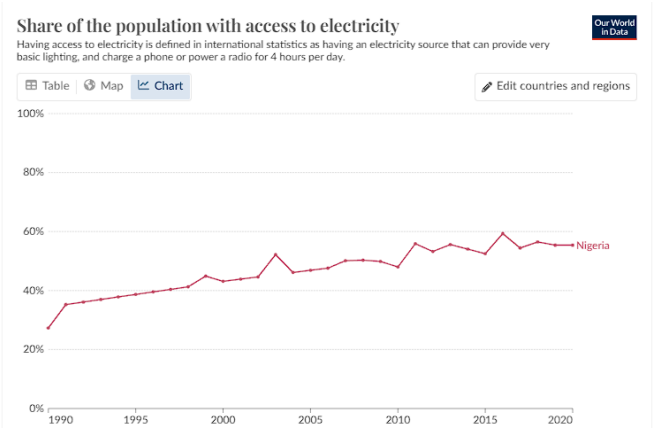
CURRENT SITUATION OF NIGERIA FROM ENERGY PRESPECTIVE

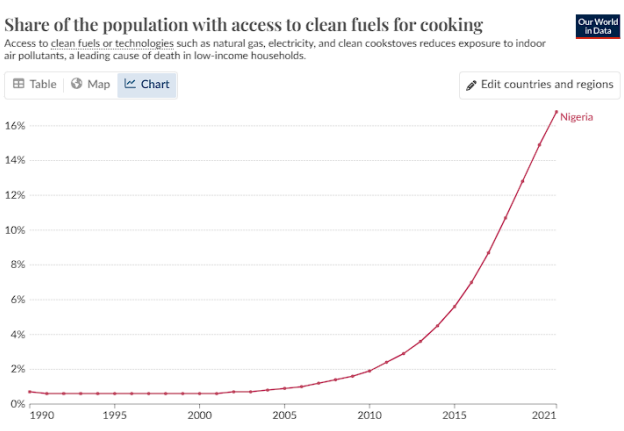
In the broader context of Africa, many countries face significant challenges in developing their energy sectors to meet the needs of their populations. While some nations like the UAE and Saudi Arabia have achieved advanced levels of development and stability in their energy infrastructure, others, including Nigeria, struggle to provide reliable and accessible energy services to their citizens.

In Nigeria, the issue isn't solely about the availability of energy resources or the capacity to generate electricity. Rather, it's a multifaceted challenge stemming from financial constraints and technological limitations. Even if the government were to extend energy access to all citizens, many individuals lack the financial means to cover the costs associated with energy consumption. This financial burden further exacerbates the disparity in energy access, particularly among marginalized communities.

Moreover, Nigeria's energy landscape is hindered by a lack of advanced technological infrastructure, which contributes to high costs associated with energy generation and distribution. Without access to cost-effective technologies and efficient energy production methods, the country faces hurdles in expanding its energy access initiatives and providing affordable services to its population.

Overall, Nigeria's energy sector faces complex issues beyond mere resource availability, including financial constraints and technological limitations. Addressing these challenges requires a comprehensive approach that combines investment in infrastructure, innovation in technology, and policies aimed at promoting equitable access to energy services for all citizens.

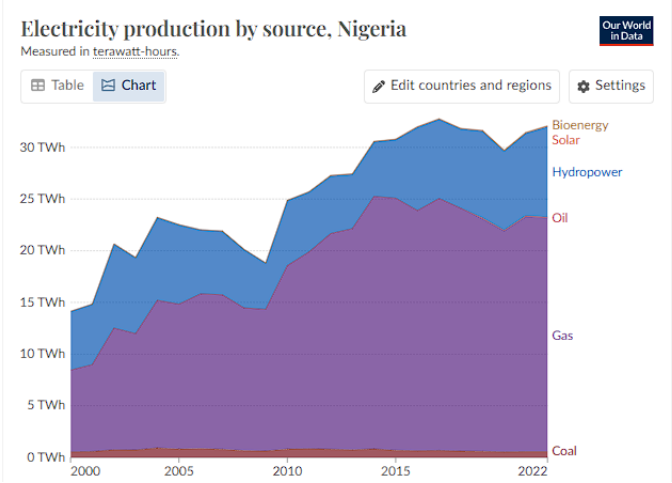


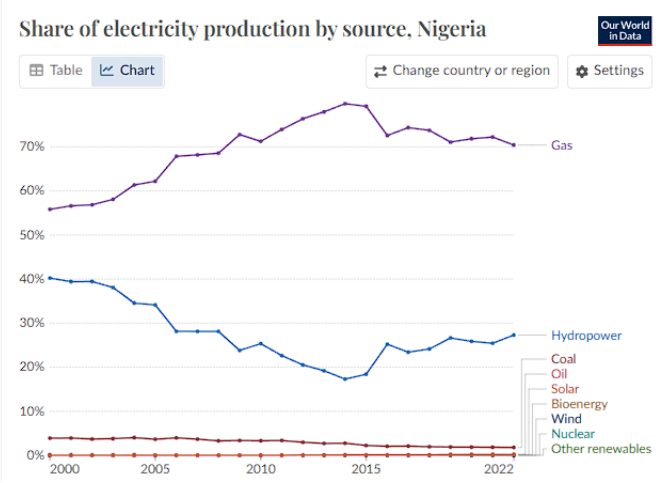


These things can be verified from the data shown above.

Energy Resources in Nigeria

For this we by will start by seeing the electricity production sources of the country as electricity is the most common and useful energy. Nigeria uses about 544TWh primary energy in year 2021 and produces about 32.11TWh of electricity there is huge difference between both it is due to the efficiency of electricity generation and much of this primary energy is consumed for other tasks too like cooking.





Fossil Fuels

Oil:

- Nigeria is a major African oil producer, with vast reserves in the Niger Delta.
- Oil fuels the economy, providing revenue and driving industrial growth.
- International and state-owned companies are involved in exploraction and production.
- Nigeria produces about 1.5 million barrels of oil per day.

Natural Gas:

- Abundant natural gas reserves complement Nigeria's oil wealth.
- Used for electricity, industry, and domestic purposes.
- Efforts to develop the sector aim for economic diversification and exports.
- Nigeria has the largest gas reserves in Africa, with an estimated 200 trillion cubic feet of gas.

Coal:

- Nigeria has significant coal reserves, mainly in the southeast.
- Limited production due to economic and environmental concerns.
- Potential interest in revitalizing coal for energy generation.

Nuclear

The country possesses little to no nuclear resources and there are no nuclear plants in Nigeria.

RENEWABLE

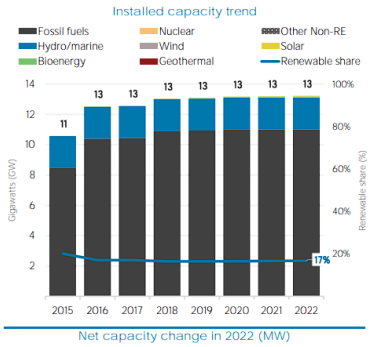
SOLAR - Nigeria has high solar resource potential characterised by an average annual global horizontal irradiation ranging between 1 600 kilowatt hours per square metre (kWh/m^2) and 2 200 kWh/m^2.

WIND - The country has moderate wind potential with average wind speeds at 10 metres (m) height ranging between 2.1 m/second (s) and 8 m/s with the highest values (greater than 7 m/s) located in the northern part of the country

HYDRO- Nigeria has a large hydro potential of around 24 GW and a small hydro potential of about 3.5 GW. This potential for the most part is yet to be exploited. In 2015, Nigeria had about 1.9 GW installed capacity of large hydro and about 60 megawatts of small hydro.

BIOMASS - Exploiting the huge potential of biomass resources in the country, especially in the form of agricultural residues for power generation, will go a long way to resolving the current energy crisis in Nigeria.

Energy resource	Unit	2015	Total	Percentage utilised in 2015
Large hydro	GW	1.9	24	8%
Small hydro	GW	.06	3.5	2%
Wind	GW	0	3.2	0%
Bioenergy	PJ	1 229	29 800	4%
Solar PV	GW	0.017	210	0%
CSP	GW	0	88.7	0%



ENERGY CONSUMPTION

Energy consumption is the final goal of all this we are producing the energy to use it in different place and the main consumption of energy is in form of electricity, fuel in transport, cooking fuel or heating applications. So we will look at the data of consumption in each sector and also see the usage of different resources in transport sector as it is major usage after electricity and household usage.

Figure 4 Total final energy consumption by sector in Nigeria 2015 (2 155 PJ) based on model results and validated through a range of stakeholder engagement

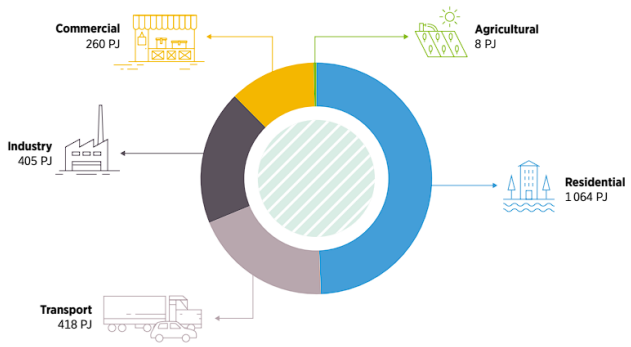
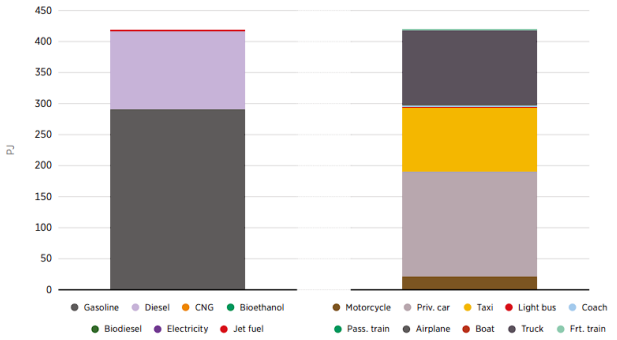


Figure 8 Total final energy consumption in transport in 2015 (PJ) based on model results and validated through a range of stakeholder engagement



Note: CNG = compx-ressed natural gas.

POLITICAL

Politics also greatly effects the energy sector of any country as all the major decision regarding energy in a country are taken by government and government policies greatly affects the energy distribution in a country.

Policy Making:

- The Nigerian government plays a central role in formulating energy policies and regulations that govern the exploration, production, and distribution of energy resources.
- Political decisions often influence the allocation of licenses, permits, and contracts to companies involved in the energy sector, including oil and gas exploration, power generation, and renewable energy projects.

State-Owned Enterprises:

- The Nigerian National Petroleum Corporation (NNPC) is a state-owned entity responsible for the management and regulation of the oil and gas industry in Nigeria.
- NNPC's operations and decision-making processes are influenced by political interests, with the government exerting control over key strategic decisions, revenue allocation, and resource management.

Resource Allocation:

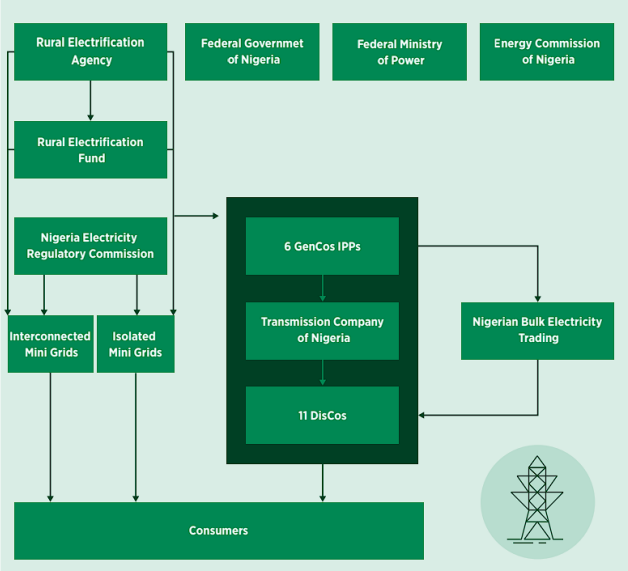
- Control over energy resources, particularly oil and gas reserves, has significant implications for Nigeria's economy, fiscal policies, and geopolitical relationships.
- Political actors often negotiate resource allocation and revenue-sharing arrangements, which can impact regional development, intergovernmental relations, and socio-economic disparities.

Investment Climate:

- Political stability and governance issues influence the investment climate in Nigeria's energy sector, affecting foreign direct investment, project financing, and market competitiveness.
- Policy uncertainty, regulatory changes, and corruption perceptions can deter investment and hinder the development of energy infrastructure and projects.

International Relations:

- Nigeria's energy sector is closely intertwined with its international relations, particularly through partnerships, trade agreements, and diplomatic engagements with other countries and multinational corporations.
- Political considerations, such as diplomatic alliances, economic interests, and security concerns, shape Nigeria's energy diplomacy and engagements with global energy markets.



REFINING/ CONVERSION INFRASTRUCTURE FOR FOSSIL FUELS

Nigeria has a significant refining/conversion infrastructure for fossil fuels based energy supply. The country has four refineries, with a combined capacity of 445,000 barrels per day (bpd). However, these refineries are not operating at full capacity, and Nigeria imports a significant amount of refined petroleum products. In addition to the refineries, Nigeria also has a number of natural gas processing plants. These plants process natural gas into products such as methane, ethane, propane, and butane. The country also has a number of fertilizer plants that convert natural gas into ammonia and urea.

Refinery	Location	Capacity (bpd)
Warri Refinery and Petrochemical Company	Warri, Delta State	125,000
Kaduna Refinery and Petrochemical Company	Kaduna, Kaduna State	110,000
Port Harcourt Refinery Company	Port Harcourt, Rivers State	210,000
Dangote Refinery	Lekki, Lagos State	650,000 (under construction)

Refineries

Plant	Location	Capacity (mmcf/d)
Bonny River Natural Gas Liquefaction Plant	Finima, Bonny Island, Rivers State	2,500
Brass LNG	Brass, Bayelsa State	5,000 (under construction)
Olokola LNG	Olokola, Ogun State	10,000 (under construction)
Escravos Gas Plant	Escravos, Delta State	1,200
Obiafu-Obrikom Gas Plant	Obiafu, Rivers State	400

Natural Gas processing plants

The Nigerian government is working to expand the country's refining/conversion infrastructure. The Dangote Refinery is expected to come online in 2023, and the government is also planning to build a number of new natural gas processing plants.

The expansion of Nigeria's refining/conversion infrastructure will help the country to reduce its dependence on imported refined petroleum products and to generate more revenue from its natural gas resources.

HYDROPOWER

Nigeria has several operational hydropower plants, including the Kainji, Jebba, and Shiroro dams on the Niger River, which are among the largest in the country and there are some other significant ones like Zungeru Hydropower Plant, Mambilla Hydropower Plant, Kiri Hydropower Plant, Dadin Kowa Hydropower Plant, Kafin Zaki Dam and there are many other small scale plants. These hydropower facilities have a combined installed capacity of over 2,000 megawatts (MW) and contribute a significant portion of Nigeria's electricity supply. Kainji, Jebba, and Shiroro are all medium or high head hydroelectric power plants and uses Francis turbines.

Challenges and Opportunities:

- Despite its potential, Nigeria's hydropower sector faces challenges such as inadequate infrastructure, funding constraints, and environmental concerns.
- Limited investment in maintenance and upgrades has led to operational inefficiencies and reduced capacity utilization at some hydropower plants.
- However, there are opportunities for further development of hydropower resources in Nigeria, including the construction of new dams and the rehabilitation of existing facilities to increase generation capacity and improve reliability.

Progress in renewable energy deployment and its resource wise breakup

Nigeria has advanced considerably in the use of renewable energy in recent years. Nigeria had 2,920 megawatts (MW) of installed renewable energy capacity in 2020. This had grown to 4,820 MW by 2023.In Nigeria, solar energy is the most common renewable energy source. Nigeria possesses a substantial solar energy resource, with a potential of 2,600 gigawatts (GW). Nigeria is also making better use of its wind and hydropower resources.

With several regulations and initiatives, the Nigerian government is promoting the growth of renewable energy. As an illustration, the government launched the Renewable Energy Feed-in Tariff (REFIT) program, which offers financial incentives to companies who create renewable energy. In addition, the government has created the National Renewable Energy Action Plan (NREAP), which lays out goals for the use of renewable energy.

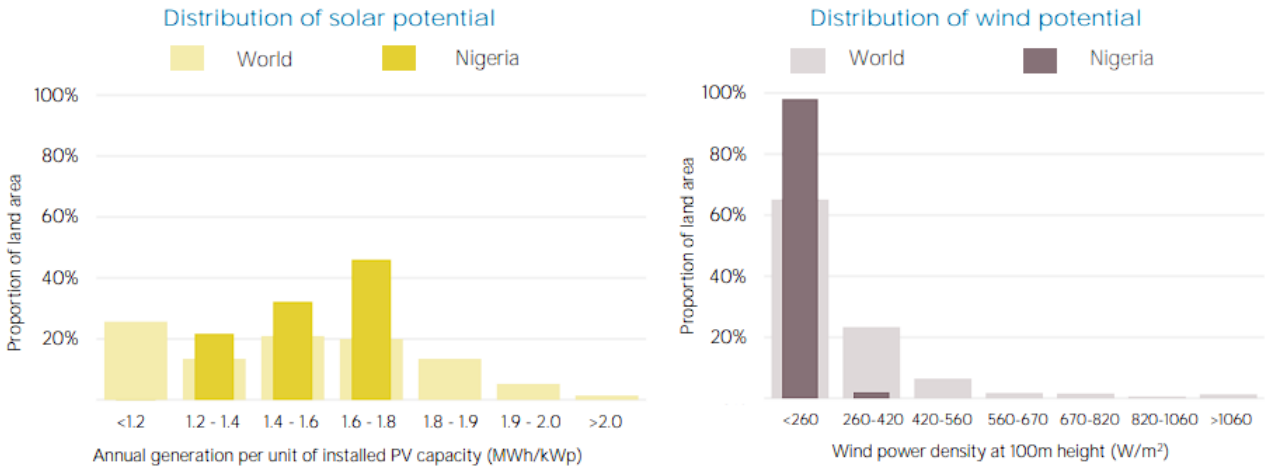
Nigeria is benefiting from the growth of renewable energy in terms of employment creation, improved energy security, and decreased dependency on fossil fuels.

Here are some particular instances of Nigeria's use of renewable energy:

1. In 2022, the 30 MW Katsina Solar Power Plant went into operation.

2. In 2021, the Gurara Hydropower Plant, a 30 MW hydropower facility, was put into service.

3. It is anticipated that the 240 MW Kankiya Wind Farm would come online in 2024.



A Historical Perspective

1. Pre-Industrial (Agricultural) Era (Up to Mid-1800s)

- During this era, Nigeria primarily relied on traditional biomass for energy. Wood, agricultural residues, and animal dung were essential for cooking, heating, and lighting. There was some use of coal.

- Economic activities were largely agrarian, and energy needs were met through local resources.

2. Early Industrial (Advanced Metallurgy) Era (Late 1800s)

- As Nigeria entered the early industrial phase, advanced metallurgy played a role in energy use. And there is use of coal and use of oils like kerosene.

- The extraction and processing of minerals and metals required energy, albeit on a smaller scale compared to later eras.

3. Industrial (Steam Engines) Era (Early to Mid-1900s)

- The advent of steam engines marked a significant shift in Nigeria's energy landscape and there was increase in use of coal.

- Steam-powered machinery, railways, and factories demanded more substantial energy sources like coal.

4. Late Industrial (Dynamo, Internal Combustion Engines) Era (Mid to Late 1900s)

- The mid-20th century witnessed the rise of dynamo-powered systems and internal combustion engines.

- Electricity generation, transportation, and industrial processes relied on these technologies.

5. Modern Era (Early 2000s Onwards)

- In recent decades, Nigeria has embraced the information era characterized by microprocessors, digital technologies, and telecommunications. And there is increase in use of every energy resource by a huge margin and some new technologies were also used enormously like solar pv, wind turbines.

- The demand for electricity for household applications, industrial and transport (electric cars) have surged.

Key Influences on Nigeria's Energy Transitions

Trading Relations: Nigeria's energy choices have been influenced by a long history of trading relations with other nations.

External Interference: Decisions related to energy infrastructure were often shaped by external interference in domestic policymaking.

Resource Discoveries: The discovery of energy resources (such as oil) significantly impacted Nigeria's energy trajectory.

Technology Development: Technological advancements played a crucial role in shaping energy transitions.

BASIC COMPONENTS OF ENERGY SYSTEM

ENERGY SOURCE

This could be fossil fuels (such as coal, oil, or natural gas), nuclear fuel, biomass, sunlight (for solar energy), wind (for wind energy), water (for hydroelectric power), or geothermal heat. Nigeria is rich in fossil fuels but lack nuclear fuel. Similarly Nigeria have abundance of solar and hydro resources but lack others.

Energy Conversion System

This covers the devices or methods used to transform the energy from the source into electrical power. For instance, hydroelectric power plants employ water turbines, but fossil fuel and nuclear power plants often use steam turbines. Nuclear power plants and wind turbines are other sources of electricity produced directly from sunlight through solar photovoltaic (PV) systems. Nigeria have a decent Energy Conversion System with no nuclear power plants and 3 main hydro powerplant and a little solar plants.

Transmission and Distribution System:

Once electricity is generated, it needs to be transmitted over long distances from power plants to distribution networks and eventually to consumers. The transmission system consists mainly of high-voltage power lines, transformers, substations, and other equipment. Transmission System is nothing but a power grid in which we put electricity from different sources. There are many factors affecting grid like in case there are synchronous machine in grid the more there are the more stable will they be and we up and down voltages at different stages. Like for long distance we up it and make it high-voltage and then for distribution we make it low-voltage.

Control and Protection Systems:

These systems monitor and control the operation of power plants, transmission lines, and distribution networks to ensure safe and reliable electricity supply. They also provide protection against faults, such as short circuits and overloads, which could damage equipment or cause power outages.

Fuel Handling and Storage (for fossil fuel power plants):

Fossil fuel power plants require facilities for storing and handling fuel, such as coal yards, oil tanks, or natural gas pipelines. These components ensure a steady supply of fuel to the power plant throughout the year.

Some of the shortfalls that have been observed in implementation of targeted energy goals of the country.

The biggest shortfall of the country is lack of economic resources which lead to all types of problems like lack of technology, poor maintenance, limited access to electricity to people, fuel pricing, Energy theft and no payment. And then there are some others like Policy and Regulatory Challenges and Environmental Concerns.

Limited investment in energy infrastructure has hindered the development and expansion of power generation, transmission, and distribution facilities. Inadequate funding has led to delays in project execution and the inability to meet growing energy demand. And this lack of investment lead to second biggest problem which is infrastructure challenges like aging power plants, transmission losses, and inadequate distribution networks. Poor maintenance practices and limited upgrades contribute to inefficiencies and reliability issues in the energy supply chain. And due to all these problems country have to import fuel and sometimes even electricity and this expose country to supply chain disruptions and price volatility. High transmission and distribution losses, often due to technical inefficiencies and electricity theft, result in revenue losses for utilities and undermine efforts to improve service reliability and affordability. Addressing these losses requires investments in grid modernization and loss reduction initiatives.

Safety and Disaster protocols

With having a good energy system safety and disaster protocols are also important and like each country Nigeria also focuses on it.

Worker Safety:

Policy Example: The NNRC enforces regulations mandating power plants to develop and implement safety programs that include worker training on hazard identification, safe work practices, and emergency procedures. The FMP promotes similar guidelines for non-nuclear facilities.

Additional Points: These programs should address specific hazards like high voltage equipment by requiring proper PPE like insulated gloves and adherence to lockout/tagout procedures.

Public Safety:

Policy Example: The National Environmental Standards and Regulations Enforcement Agency (NESREA) requires power plants to conduct Hazard Identification and Risk Assessments (HIRA) and develop Emergency Response Plans (ERPs) that consider potential accidents and their impact on nearby communities.

Additional Points: ERPs should include evacuation plans, communication protocols to alert residents, and drills to ensure community preparedness.

Environmental Protection:

Policy Example: The NESREA sets air and water quality standards for power plant emissions. They also enforce regulations on hazardous waste management.

Additional Points: Power plants must implement measures like flue gas desulfurization systems to reduce air pollution and proper wastewater treatment facilities to minimize environmental impact.

Asset Protection and Business Continuity:

Policy Example: The Nigerian Electricity Regulatory Commission (NERC) enforces a framework for preventive maintenance of power plant equipment. This includes regular inspections and adherence to manufacturer's recommendations.

Additional Points: Investing in backup power generation systems and robust cybersecurity measures can further enhance business continuity during disruptions.

Regulatory Compliance:

Examples: Power plants in Nigeria must comply with regulations set by various agencies like NNRC, NESREA, NERC, and FMP. These cover aspects like safety protocols, environmental standards, and reporting requirements.

Public Confidence:

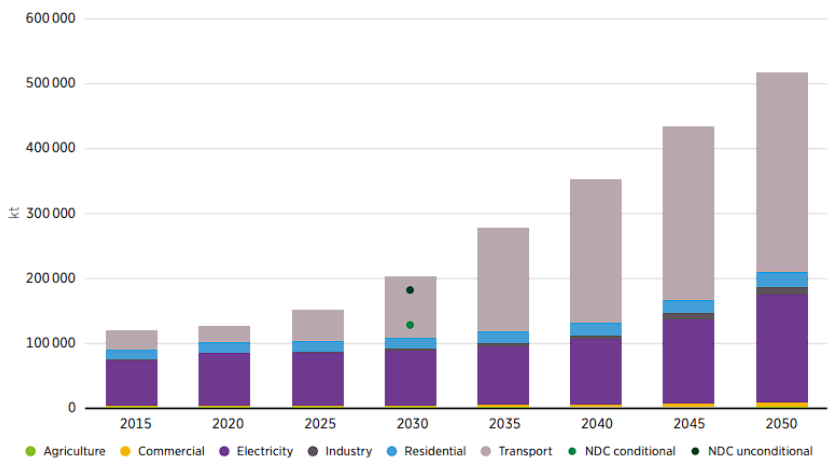
Recommendation: Power plants can build public trust by conducting transparency initiatives, such as public tours, information sessions, and publishing environmental performance reports.

By implementing these policies and fostering open communication, power plants in Nigeria can operate safely, minimize environmental impact, and ensure a reliable electricity supply for the nation.

POLLUTION

Pollution is a very big problem in energy sector as all types of energy generations do pollution like in thermal plants there is release of harmful gases like CO_2 and in nuclear there is nuclear waste and in solar pollution done during making of solar panels, etc. We can see the challenge the pollution possess by looking at a expected data of CO_2 emission in future.

Figure 14 CO_2 emissions by sector based on current plans and policies



Note: kt = kilotonnes.

Air Pollution from Fossil Fuel Combustion:

- Nigeria's heavy reliance on fossil fuels, particularly oil and gas, for electricity generation contributes to air pollution.
- The combustion of fossil fuels releases pollutants such as sulfur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM), and carbon dioxide (CO2) into the atmosphere, leading to air quality issues and respiratory health problems.
- Emissions from power plants, industrial facilities, and vehicular traffic are major sources of air pollution in urban areas, especially in cities like Lagos and Port Harcourt.

Water Pollution from Oil Spills:

- Nigeria's oil industry, concentrated in the Niger Delta region, has been plagued by frequent oil spills and leaks, leading to water pollution.
- Oil spills contaminate water bodies, wetlands, and farmland, posing threats to aquatic ecosystems, biodiversity, and the livelihoods of local communities that rely on fishing and agriculture.
- Poorly maintained infrastructure, pipeline vandalism, and operational accidents contribute to the occurrence of oil spills and the degradation of water quality.

Land Pollution and Habitat Destruction:

- Oil exploration and production activities in Nigeria have also resulted in land pollution and habitat destruction.
- Spilled oil can seep into the soil, contaminating agricultural land and reducing fertility. Cleanup efforts may be inadequate, leaving contaminated sites untreated.
- Habitat destruction due to oil infrastructure development, such as pipelines, roads, and drilling sites, further exacerbates environmental degradation and loss of biodiversity.

Waste Management Challenges:

- The energy sector, including power generation and oil production, generates significant amounts of waste, including hazardous materials and byproducts.
- Inadequate waste management practices, such as improper disposal and lack of treatment facilities, contribute to pollution and environmental degradation.
- Efforts to improve waste management infrastructure and promote recycling and pollution control measures are essential for mitigating environmental impacts.

Climate Change Implications:

- The combustion of fossil fuels in Nigeria contributes to greenhouse gas emissions, exacerbating global climate change.
- Rising temperatures, changing precipitation patterns, and extreme weather events pose risks to agriculture, water resources, and human health in Nigeria and beyond.
- Transitioning to cleaner and renewable energy sources, improving energy efficiency, and implementing climate mitigation strategies are essential for addressing the long-term impacts of pollution on climate and sustainable development.

ACTIONS THAT NEEDS TO BE TAKEN TO IMPROVE THE SITUATION

Power

- Improve the existing financing mechanisms and explore further regulatory options. Fostering innovative financing mechanisms for distributed renewables and utility-scale technologies.
- Improve and expand the regulatory framework for decentralised renewable energy solutions.
- Accelerate electrification of end uses and promote policies that would support it.
- Modernise the transmission and distribution infrastructure.
- Invest in renewable over fossil energy. The analysis shows that it is cost-effective to invest in renewable energy technologies over fossil fuels such as coal, owing to the declining costs of renewables.
- Develop a robust database for renewable energy potentials and a corresponding pipeline of bankable projects.

Buildings

- Improve upon existing efforts to promote clean cooking. Despite the decades of efforts to promote clean cooking in Nigeria, around 80% of Nigerians still do not have access to clean cooking facilities. This can be attributed to a lack of affordable alternatives which subdues the ability of households to transition to clean cookstoves.
- Improve upon existing appliance efficiency and lighting programmes. The majority of electricity consumed in the residential and commercial sectors is through lighting, refrigeration, air conditioning and miscellaneous electrical appliances. For lighting, the replacement of incandescent light bulbs with light-emitting diodes (LEDs) and other efficient lights can bring about large energy savings as observed in the TES for the residential/commercial sector.

Transport

- Faster adoption of biofuels.
- Policies aimed at transport electrification and acceleration of the adoption of electric vehicles (EVs) should be put in place.
- Enhancement of public transportation offerings and rail infrastructure driven by renewables will be key to achieving the modal shifts and energy efficiency needed in transportation.

Industry

- Develop local renewable energy technologies manufacturing industries.
- Focus on energy efficiency improvement in small and medium-sized enterprises (SMEs)
- Promote the adoption of solar heating technologies in large industries.

Agriculture

- Improve the affordability of solar irrigation pumps.
- Policies to promote the adoption of efficient pump sets.
- Incentives to promote adoption of alternative fuel tractors.

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