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SUSTAINING THE GRID WITH MORE RENEWABLE ENERGY MIX AND SMART GRID APPLICATIONS, A CASE STUDY OF NIGERIA'S GRID NETWORK

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Abstract - *This study examines problems with Nigeria's grid network and suggests a long-term fix: using smart grid technologies to increase the proportion of renewable energy sources. It seeks to improve commercial opportunities in the power industry, decrease greenhouse gas emissions, increase access to electricity, and integrate more renewable energy sources. The study makes use of the PRISMA paradigm in conjunction with a systematic literature review to guarantee data quality. It addresses issues including transmission networks, power limitations, Nigeria's existing electricity status, renewable energy integration, smart grid adoption, and state of play. The results advocate for enhanced forecasting, demand response initiatives, energy storage, and other long-term solutions through the integration of renewable energy sources. The paper suggests legislative actions to encourage the use of smart grid technologies in order to improve the electricity industry, create jobs, and maintain environmental sustainability. It provides a comprehensive examination of the limitations of the electrical system and suggests workable fixes. For efficient and sustainable energy generation, this research emphasises the significance of supporting smart grid technologies and environmentally friendly legislation. It is beneficial to academics, industry practitioners, policymakers, and the discourse surrounding renewable energy and sustainable development in Nigeria.*

***Key Words*: *Smart grid technology, Renewable energy, Grid network, Sustainable energy, Non-renewable energy*.**

1. INTRODUCTION

There are a number of problems with Nigeria's power grid system that impact the country's transmission, distribution, and supply of electricity. Among these problems are inadequate infrastructure, insufficient technical and financial losses, and restricted access to electricity in isolated places (Emeasoba, 2018). Due to these issues, Nigeria's economy and society have been significantly impacted by an inconsistent electricity supply. Nigeria's excessive reliance on non-renewable energy sources has had a negative impact on both the environment and the health of its citizens. Nigeria has substantial untapped renewable energy resources that might be used to diversify the country's energy sources and reduce its reliance on fossil fuels, such as hydroelectricity, wind, and solar energy (Emeasoba, 2018). However, the country's energy mix is dominated by non-renewable energy sources like oil and gas. As a result, both Nigeria's natural resources and citizens' health have suffered due to environmental degradation. Fossil fuels account for the majority of Nigeria's energy production, which increases carbon emissions and the country's reliance on imported fuel. The integration of renewable energy sources into the Nigerian electrical system is beset by significant technological and economical challenges. For example, the grid system needs to be flexible because renewable energy sources are sporadic. The massive infrastructure investment required to incorporate renewable energy sources into the grid system might be beyond the nation's means. Implementing smart grid technologies may be expensive and requires hiring of specialists with the necessary skills, which may not exist in the nation (Nwosu and Iwu-James, 2019).
As the country's population grows, more power is needed, the grid has also been severely plagued by system failure and frequent interruptions, necessitating interventions from foreign governments and technical partners over the years. As a result, the government has put forth a plan (vision 30:30:30) to increase generation capacity and expand the grid in order to accommodate and deliver dependable power. By 2030, the Nigerian government's 30:30:30 strategies are to generate 30GW of electricity, with 30% of that energy coming from renewable sources (Kabeyi and Olanrewaju, 2022). With the aid of smart grid technologies, it is essential to move towards a more sustainable energy mix by integrating renewable energy sources into the grid system. Solar, wind, and hydropower are examples of renewable energy sources that are clean, plentiful, and have the potential to lessen Nigeria's dependency on fossil fuels. Nigeria may reduce its carbon footprint and improve the stability and dependability of its electricity supply by incorporating these sources into the current infrastructure (Adeniyi, *et al.,* 2019).

In order to boost automation and enable real-time monitoring, smart grid technology entails integrating cutting-edge digital communication and control technologies into the conventional electrical grid. This technology makes it possible to integrate renewable energy sources and optimize energy use, which improves energy reliability and efficiency (Nwanji, *et al.,* 2020).

The substantial difficulties the Nigeria's power grid system faces and the possible advantages of switching to a

sustainable energy mix serve as the justification for this study's reasoning. These challenges include poor infrastructure for power production, distribution, and transmission, substantial technical and economic losses, as well as environmental degradation (Ministry of Power, 2019). Hence, the use of smart grid technology, integrating renewable energy sources into the grid system has the ability to solve these problems and advance sustainable development. Therefore, this paper will provide insight on the environmental, economic, and technological aspects of Nigeria's transition to a mix of renewable energy sources, which can help stakeholders and policymakers decide on the best course of action.

1.1 The aim of the study

This research aims to recommend a sustainable solution that will usher in efficient stability in Nigeria's grid network with more renewable energy mix, while also addressing other technical challenges faced by the Nigerian electricity grid system.

1.2 Objectives of the study were to:

i. To identify the technological difficulties the Nigerian electricity grid system has that prevent the grid network from incorporating renewable energy sources.
ii. To assess the Nigerian grid system's current capacity and calculate the additional renewable energy capacity needed to achieve effective stability.
iii. To suggest a framework for public policy that promotes investment in infrastructure of energies that are renewable and foster the expansion of regional businesses and generates employment possibilities.
iv. To make recommendations on how to minimize greenhouse emissions, by expanding the share of renewable energy in Nigeria's grid network, in line with international initiatives to slow down climate change.
v. To make recommendations for the best practices and methods to use when running a grid in order to reduce or completely avoid system collapse, increase grid reliability, boost energy efficiency, and integrate smart grid solutions, with a timetable for implementation within the next five years.

2. Review of related literature

Dubbed "the giant of Africa," Nigeria struggles with 50.9% energy access, which impedes economic development. The country's reliance on a fossil fuel-powered, centralised grid is beset by several problems such as deteriorating electricity generation and distribution infrastructure as well as increasing demand. Education, healthcare, and agriculture were among the the major industries that suffer. Integration of renewable energy sources and smart grid technologies are being used as solutions to this problem. (Pudjianto *et al*., 2018; World Bank, 2022).

2.1 Overview of Nigeria's power grids

The National Electric Power Authority (NEPA), which was founded in 1972 and subsequently renamed Power Holding Company of Nigeria (PHCN), was one of the major changes to the 1898-old Nigerian electric grid. In order to address capacity and efficiency difficulties, PHCN was divided into 18 firms by the Power Reform Act by 2005, with the goal of privatisationwhere independent Power Plants played a key role in this change. Even with a sophisticated network made up of generating, transmission, and distribution components, problems still exist because of low investment, inadequate upkeep, and vandalism of infrastructure, which results in frequent outages and limited access to energy (Nwakali and Iwuoha, 2020). The integration of renewable energy sources, industry privatisation, and anti-vandalism laws are the solutions. The primary source of energy is hydroelectricity, however thermal plants also contribute. Low-voltage lines help with distribution, while high-voltage lines manage final delivery (Nwakali and Iwuoha, 2020).

2.2 Renewable energy integration

Several studies point out obstacles to Nigeria's grid's integration of renewable energy, these obstacles include inadequate funding, inadequate infrastructure, and lax laws (Adeniyi et al., 2019). Notwithstanding obstacles, there is acknowledgement of significant advantages such as improved energy security, decreased emissions, and economic expansion (Adebayo et al., 2018). Encouraging regulatory environments, infrastructure expenditures, and strong government support are essential for successful integration of renewable energy into the Nigerians energy mix.

2.3 Smart grid technology

Implementing smart grid technology is crucial for strengthening Nigeria's power grid resilience. Previous attempts have been hindered by issues like insufficient investment, poor infrastructure, and a lack of awareness about the benefits of smart grids. However, studies suggest significant advantages, including enhanced energy stability, efficiency, and better integration of renewable sources. The Nigerian Vision 30:30:30, a national development strategy, aims to increase electricity production to 30,000 megawatts and provide access to at least 80% of the population by 2030, underscoring the importance of smart grid investment and policy support.

2.4 The current electricity situation in Nigeria

Nigeria's electrical supply condition is characterized by a lack of supply, a lack of infrastructure and excessive pricing (Okenyi, 2021). This condition is examined one after another.

2.4.1 The current power generation in Nigeria

The Nigerian Electricity Regulatory Commission (NERC) reported that as of December 2020, the nation's electricity generation capacity was 12,522 MW, while actual generation averaged 4,175 MW, resulting in a large supply deficit (NERC, 2021). Seven of the twenty-three generation stations are more than twenty years old, and the average daily power generation is less than the peak anticipated for the current infrastructure. Despite the planned capacity projects for a better future, Nigeria's power generation situation currently presents challenges. These include a lack of available generation, delayed facility maintenance, inadequate funding for power plants, outdated tools, safety facilities, and operational vehicles, outdated communication equipment, a lack of exploration to tap all sources of energy from the available resources, and low staff morale (Emodi, *et al.,* 2014).

2.4.2 Nigeria transmission system

Nigeria's transmission network consists of 32 330/132 kV substations and long transmission lines measuring 6801.49 km for 132 kV and 5523.8 km for 330 kV, with a combined capacity of 7688 MVA. In addition, there are 105 substations with a 9130 MVA capacity operating at 132/33/11 kV. Nevertheless, the grid has significant power outages because of the lengthy transmission lines, especially on routes like Benin-Ikeja West, Oshogbo-Benin, Jebba-Shiroro, Birnin Kebbi-Kainji, Jos-Gombe, and Kaduna-Kano (Emodi, et al., 2014). Nigeria's economy has been hindered by a lack of energy, which has increased manufacturing costs and interfered with business operations. Growing energy use puts stress on the transmission and distribution networks, which can result in systemic breakdowns and unstable power supplies. As a result, people and companies turn to pricey substitutes like solar PV systems and diesel generators. In many states, access is limited due to the transmission grid's vulnerability to disruptions. Significant obstacles encompass insufficient federal funding, poor electrical capacity, antiquated grid segments devoid of redundancies, recurrent acts of vandalism, overloading transformers, insufficient spare parts, and inadequate security and surveillance (Emodi, et al., 2014).

2.4.3 Nigeria power constraint

Despite having an installed power generation capacity of 10,390 MW, Nigeria suffers from a substantial power deficit. The nation should ideally produce about 174,508 MW to suit its demands, but actual generation is still less than 6,506 MW, despite having a population of over 174 million (Emodi, et al., 2014). Despite Nigeria's remarkable 6% to 8% growth rate, this deficit has an influence on economic growth. In contrast, South Africa generates more than 45,000 MW of power while having a population that is less than one-third that of Nigeria (Emodi, et al., 2014). Privatisation, reforms, and renewable energy initiatives are among the measures taken to improve Nigeria's electrical condition; yet, issues including low supply, shoddy infrastructure, and exorbitant prices still exist. The Oshogbo National Grid, which was put into service in 1983, is essential for transferring electricity from southwestern power plants. On the other hand, it has problems with deteriorating infrastructure, malfunctions, vandalism, and sabotage (Ogbonna, *et al.,* 2020). The Nigerian government has taken a number of steps to solve these problems, including as establishing power purchase agreements with private companies to construct new power plants and upgrade infrastructure. Moreover, initiatives like the National Energy Efficiency Action Plan seek to lower the demand for electricity while increasing energy efficiency (Ezennia, 2018).

2.5 The current state of the Nigerian energy grid system in terms of renewable energy integration and smart grid technology

Nigeria produces most of its electricity from fossil fuels, mostly natural gas, with very little help from renewable sources. Just 0.1% of electricity is produced by renewable energy sources like solar and wind, despite their enormous potential (NERC, 2021). The objective of 30% renewable energy by 2030 and programmes like the Renewable Energy Feed-in Tariff (REFiT) programme attempt to incorporate renewable energy sources into the grid, as fossil fuels now account for 85% of electricity output (IRENA, 2019). Although the nation's smart grid infrastructure is still in its infancy, programmes such as the NEP seek to advance rural electrification through the use of smart mini-grid technologies (NERC, 2021). All things considered, moving to a system powered by renewable energy necessitates significant financial outlay, cooperation from all parties involved, and thorough environmental evaluations (World Bank, 2021).

2.6 Renewable energy status

The use of renewable energy sources, such as solar, wind, and hydro power, can help to reduce the dependence on fossil fuels and mitigate the negative impacts of traditional power generation on the environment (Kammen and Peters, 2010). The following are renewable energy sources and their benefits, similarly the influence of the introduction of the smart grid technology into the Nigerian energy grid system.

2.6.1 Wind energy

Nigeria might benefit greatly from wind energy by producing affordable, sustainable electricity, especially in the north where wind speeds can reach nine metres per second (Ibrahim, *et al*., 2020). However, obstacles such a lack of funding sources, policy backing, and infrastructure prevent it from being used (Ogwueleka and Nnabuchi, 2020). The government must pass laws that encourage wind energy use, provide incentives like tax cuts and feed-in tariffs, and make investments in vital infrastructure like transmission lines if it is to realise the full potential of wind energy. In order to improve the efficiency and dependability of wind energy technologies through partnerships with domestic and international partners, research and development efforts are

also essential (Adeoye, *et al.,* 2019). According to the National Renewable Energy and Energy Efficiency Policy, wind energy has a potential capacity of over 10,000 MW. This means that wind energy might play a major role in helping Nigeria meet its target of producing 30% of its electricity from renewable sources by 2030 (Ibrahim, et al., 2020).

2.6.2 Solar renewable energy

With an average daily solar radiation of 5.5 kWh /m^2/, Nigeria has an abundance of solar resources. Solar energy has the potential to supply evenly distributed, reasonably priced, and sustainable electricity nationwide (Oyedepo, *et al.,* 2020). Its use is hampered by high initial expenditures, inadequate infrastructure, and weak policy backing. The government should provide tax breaks, feed-in tariffs, and infrastructural funding to increase the use of solar energy (Fagbenle, *et al.,* 2020). In line with Nigeria's Vision 30:30.30, solar energy can lower emissions and improve energy security. The development of solar energy is being fuelled by government initiatives, private sector involvement, and international backing, despite obstacles including low investment and lax regulatory frameworks (Adebayo, *et al.,* 2018). Nigeria needs to invest in infrastructure, adopt laws that support it, and encourage research and development of solar technology if it is to realise its full potential (Adeniyi, *et al.,* (2019).

2.6.3 Hydroelectric energy

Nigeria has a lot of potential for hydroelectric power, especially considering how many big rivers it possesses, such the Niger and Benue (generation (Adelabu, *et al.,* 2020). However, due to issues including insufficient finance, infrastructure, and policy support, it is still underutilized (Olawale, *et al.,* 2020). The government should provide favourable policy conditions and incentives to draw in investments from the private sector in order to realise this potential (Adelabu et al., 2020). This could involve feed-in tariffs, tax breaks, and other forms of financial assistance. Moreover, integrating hydroelectric electricity into the national grid requires spending on vital infrastructure, such as transmission lines and dams (Olawale, *et al.,* 2020). The prospective contributions of hydropower from a few states in Nigeria is shown in Table 1.

Table 1: Small hydropower potentials across some selected states in Nigeria

No.	State	River basin	Total sites	Total capacity (MW)
1.	Sokoto	Sokoto-Rima	22	30.6
2.	Kastina	Sokoto-Rima	11	8
3	Niger	Niger	30	117.6
4	Kaduna	Niger	19	59.2
5	Kwara	Niger	12	38.8
6	Kano	Hadeija-Jamaare	28	46.2
7	Borno	Chad	28	20.8
8	Bauchi	Upper Benue	20	42.6
9	Gongola	Upper Benue	28	162.7
10	Plateau	Lower Benue	32	110.4
11	Benue	Lower Benue	19	69.2
12	Rivers	Cross River	18	258.1
TOTAL			277	734.2

(Aroge, 2014).

By 2030, the Nigerian Vision 30:30:30 seeks to improve the nation's energy sector by producing 30,000 megawatts of power and providing access to at least 80% of the population (Oduwole and Ipinmoroti, (2018). Hydroelectric renewable energy can greatly aid in achieving this objective. Because hydroelectric power is clean, sustainable, and dependable, it has a lot of promise to stabilise Nigeria's energy system (Olowo, *et al.,* 2020). According to Aremu and Adekoya (2019), Nigeria might produce more than 20,000 megawatts of hydroelectric power. But obstacles like low funding, poor infrastructure, and a lack of investment prevent it from developing. Concerns are also raised by social and environmental effects, such as the uprooting of communities and the devastation of ecosystems. Government initiatives, such as tax breaks and subsidies, work in tandem with foreign aid and private sector capital to promote the development of renewable energy (IEA, 2020). Nigeria requires infrastructural investments, hydroelectric technology R&D, and a supporting policy environment in order to fully realise the potential of hydroelectric electricity (World Bank, 2020).

2.6.4 Other forms of renewable energy

Additional renewable energy sources that can be utilized to help Nigeria's government achieve its goals include: Energy from organic matter, such as wood, plants, and garbage, is converted into electricity to create biomass energy. The IEA estimates that in 2019, the usage of biomass for both power and heating increased by 1% (IEA, 2020). The heat from the Earth is converted into electricity to provide geothermal energy. The IEA reports that the installed geothermal energy capacity worldwide has increased by just 1% this year, remaining comparatively steady (IEA, 2020). The amount of energy that can be produced from biomass materials is displayed in the Table 2.

Table 1: The Amount of Energy that can be Generated from Biomass Substances

Resources	Quantity (Million Tonnes)	Energy Value (MJ)
Fuel wood	39.1	531.0
Agro-Waste	11.244	147.7
Saw Dust	1.8	31.433
Municipal Solid Waste	4.075	-

(Emodi & Samson, 2014).

2.7 Benefits of integrating renewable energy and smart grid technology into the Nigeria's energy grid system.

The benefit of integrating renewable energy sources and implementation of smart grid technology includes:

i. Reduced greenhouse gas emissions: Renewable energy sources such as solar, wind, and hydropower generate electricity without emitting greenhouse gases, which can help to mitigate climate change (IRENA, 2019).
ii. Improved energy security: Diversifying the energy mix by integrating more renewable energy sources can reduce Nigeria's dependence on fossil fuels, which are subject to price volatility and supply disruptions. This can improve energy security and reduce the country's exposure to energy price shocks (IRENA, 2019).
iii. Cost savings: Renewable energy sources such as solar and wind are becoming increasingly cost-competitive with fossil fuels, and integrating more renewable energy into the grid can help to reduce electricity generation costs (IRENA, 2019).
iv. Increased access to electricity: According to the International Energy Agency (IEA), around 50% of the population in Nigeria lack access to electricity. Integrating more renewable energy sources, particularly in rural areas, can help to increase access to electricity and improve the standard of living (IEA, 2021).
v. Improved grid stability and reliability: Smart grid technology can improve the stability and reliability of the grid by enabling real-time monitoring and control of the system. This can help to reduce the frequency and duration of power outages (World Bank, 2021).

2.8 Smart grid technology

Smart grid technology is a digital technology used to improve the efficiency, reliability, and sustainability of the electricity grid. This technology integrates advanced technologies, such as sensors, communication networks, control systems, and data analytics, to enable real-time monitoring, control, and optimization of the electricity grid. According to Faruqui, *et al.,* (2010), smart grid technology is characterized by "two-way communication and control between the utility and its customers, automation of distribution and substation operations, and advanced metering and data analytics." This information technology smart system transforms the electrical grid into an enhanced energy solution that offers real-time information on electricity demand, production, and consumption. This makes the network more dependable and better able to be sustained by a variety of renewable energy sources by predicting network characteristics like losses and adjusting for such variables while effectively integrating small-scale energy sources into the network. It is crucial to create a smart grid system that is primarily powered by renewable energy sources which use digital technology to improve the efficiency, reliability, and sustainability of the power system. Although this has the significant drawback of being intermittent, the development of IT and digitally smart devices have been made to effectively mitigate the problems with the traditional grid. Smart grids allow for the integration of renewable energy sources, distributed generation, and energy storage, which can reduce dependence on fossil fuels and improve the overall efficiency of the power system (Pudjianto, *et al.,* 2018).

2.9 Features of the smart grid technology

One of the key features of smart grid technology is advanced metering infrastructure (AMI), which involves the installation of smart meters that can measure and transmit data on energy consumption in real-time. According to Ho, *et al.,* (2016), AMI enables utilities to collect data on energy consumption and usage patterns, which can be used to optimize the grid and improve energy efficiency. Another feature of smart grid technology is distribution automation (DA), which involves the use of sensors and automation systems to monitor and control the distribution of electricity across the grid. According to Wang, *et al.,* (2018), DA can improve the reliability and resilience of the grid by detecting and isolating faults more quickly.

2.10 General smart grid features

The following characteristics of a smart grid

- Interacting with markets and customers
- Scalable and flexible for different situations
- Designed to use resources and equipment as efficiently as possible
- To avoid emergencies, be proactive rather than reactive.
- Grids that can self-heal using modern automation
- Integrated, combining maintenance, EMS, DMS, AMI, and other services.
- Having plug-and-play capabilities for ICT systems and network hardware
- Safe and trustworthy Cost-effective
- Provides monitoring and real-time data

The integration of smart grid technology into the electrical grid enables real-time monitoring and control of the grid,

allowing for the efficient integration of renewable energy sources, improved grid reliability and security, and increased integration of distributed energy resources (Griffin and Newman, 2010).

Smart grid technology also includes energy storage systems, which involve the use of battery storage systems to store excess energy generated by renewable energy sources and release it when needed. According to Li, *et al.,* (2020), energy storage systems can help to balance supply and demand on the grid and enable greater integration of renewable energy sources. Demand response (DR) is another feature of smart grid technology, which enables customers to adjust their energy consumption patterns in response to changes in electricity prices or grid conditions. According to Pudjianto, *et al.,* (2013), DR can help to reduce peak demand and improve the efficiency of the grid. Finally, smart grid technology includes micro grids, which are small-scale, self-contained electricity systems that can operate independently or in parallel with the main grid. According to (Bahramirad, *et al.,* 2014), micro grids can improve the resilience and reliability of the grid by providing backup power in the event of a grid outage. In conclusion, smart grid technology offers numerous benefits, including reduced energy costs, improved reliability and resilience, increased renewable energy integration, and reduced carbon emissions. While there are challenges and barriers to implementation, the potential benefits are substantial and could have significant implications for the future of the energy sector. Table 3 shows the disparity between smart grid and the traditional power grid.

2.11 Integrating the smart grid technology and renewable energy into the Nigerian grid system

Developing a more sustainable and effective energy system requires integrating smart grid technology with renewable energy sources (Liu, 2016). Renewable energy sources can be integrated thanks to smart grid technology, which offers real-time monitoring and control of energy production, distribution, and consumption (Liu, 2016). Due to the fluctuating and intermittent nature of renewable energy sources like solar and wind, grid operators may encounter difficulties balancing supply and demand (Liu, 2016). But, by giving real-time data on energy production and consumption, smart grid technology can assist address these issues. This will enable better energy flow prediction and control (Deng, et al., 2018).

Using energy storage devices is a crucial part of incorporating renewable energy into the smart grid system. By holding excess energy when it is available and releasing it when it is needed, energy storage systems like batteries can assist reduce the unpredictability of renewable energy sources (Deng, et al., 2018). This could lessen the demand for peaked plants that burn fossil fuels and increase grid reliability (Liu, 2016). Ultimately, the move to a more sustainable and effective energy system depends on the combination of smart grid technology and renewable energy sources (Deng, et al., 2018). Smart grid technology enables in-the-moment monitoring and management of energy production, distribution, and consumption, which can maximize the use of renewable energy sources and lessen dependency on fossil fuels (Liu, 2016). Nigeria's grid system may be improved in terms of energy access, dependability, and greenhouse gas emissions by incorporating smart grid technology and renewable energy sources (Onohaebi, 2018). Nigeria's vast renewable energy resources, such as its solar, wind, hydro, and biomass plants, might be used to help satisfy the nation's rising energy needs (Onohaebi, 2018). Renewable energy sources can be successfully integrated into Nigeria's grid system with the use of smart grid technologies. Smart grid technology can assist balance the fluctuation of renewable energy sources and provide a steady and dependable power supply by offering real-time monitoring and control of energy generation, distribution, and consumption (Akorede, et al., 2013)

The absence of energy storage facilities is a significant obstacle to integrating renewable energy into Nigeria's grid system (Onohaebi, 2018). By holding excess energy when it is available and releasing it when it is needed, energy storage systems like batteries can assist reduce the unpredictability of renewable energy sources (Deng et al., 2018). To maximize the usage of renewable energy in Nigeria's grid system, it is essential to invest in energy storage infrastructure. The requirement for advanced metering infrastructure (AMI), which enables two-way communication between the utility and customers, is a crucial component in integrating renewable energy into Nigeria's grid system (Akorede, et al., 2013). Customers can use AMI to track their energy consumption in real-time and modify their use based on the availability of renewable energy.

Nigeria can benefit from smart grid technologies in a number of ways: Firstly, it can increase the electrical grid's dependability and efficiency, which is essential for fostering economic development (Aboyade, et al., 2019). The smart grid makes it possible to monitor and manage the energy network in real-time, which can help to decrease power outages and downtime (Oyedepo, 2015).

Secondly, the benefit of smart grid technology is that it makes it easier to incorporate renewable energy sources into the grid. The smart grid can be extremely important in allowing this shift as Nigeria tries to boost the proportion of renewable energy in its energy mix (Oyedepo, 2015). A consistent and dependable power supply can be achieved by utilizing the smart grid to control the fluctuation of renewable energy sources (Oyedepo, 2015). Lastly, the smart grid can also make it possible to implement demand response programs, which can help to lower peak demand and enhance the grid system's overall efficiency (Oyedepo, 2015).

2.12 Challenges of integration renewable energy sources into the Nigerian energy grid system

The integration of more renewable energy into Nigeria's electrical grid system faces a number of obstacles despite the country's potential for renewable energy sources. The following are some of the challenges:

i. Insufficient grid infrastructure: Nigeria's current grid infrastructure was not built to support extensive renewable energy production. Since the grid is frequently unstable and prone to outages, integrating intermittent renewable energy sources like solar and wind can be challenging (Olawale, et al., 2020).
ii. Restricted financial access: The construction of renewable energy projects in Nigeria needs a considerable investment, and project developers may find it difficult to secure financial support. It can be challenging to entice private sector investment in renewable energy projects due to the high cost of capital and the absence of government policies that favor such investments (IRENA, 2019).
iii. Lack of policy support: Despite the Nigerian government's implementation of programs like the REFIT program, additional policy support is still required to promote the development of renewable energy projects. To minimize the cost of renewable energy projects, for instance, laws that offer tax incentives, subsidies, and other financial support mechanisms are required (Olawale, et al., 2020).
iv. Inadequate technical capacity: Nigeria's renewable energy industry lacks technical know-how and qualified people. This can make designing, building, and maintaining renewable energy projects challenging (IRENA, 2019).
v. Social and environmental issues: Local people occasionally oppose the establishment of renewable energy projects due to worries about land use, environmental effects, and social upheaval. The growth of renewable energy projects may be slowed down or even stopped by these worries (Olawale, et al., 2020).

2.13 Challenges facing the smart grid technology

Owing to the system's incorporation of renewable energy sources like wind and solar power, the smart grid technology is distinguished by its intermittent nature (Huang, et al., 2020). These sources' production might vary dramatically and unexpectedly because they are weather-dependent, which causes changes in the electrical supply. Due to the need for cutting-edge technologies and tactics to manage the variability of renewable energy sources, this intermittency might provide difficulties for the stability and dependability of the grid (Huang, et al., 2020). These technologies, which allow grid operators to predict and react to changes in energy supply and demand, include energy storage devices, demand response programs, and sophisticated forecasting tools.

Overall, the smart grid technology's intermittent nature emphasizes the necessity for continual innovation and investment in the creation of fresh approaches to deal with the difficulties of integrating renewable energy sources into the grid.

2.14 Policies to be implemented that promote integration of renewable energy sources and smart grid technology in Nigeria

In Nigeria, there are various policies and regulations that encourage the use of more smart grid technologies and renewable energy sources, and there are also potentials for new laws and regulations to be adopted. These are some of the policies of the Nigerian Electricity Regulatory Commission (NERC).

i. The Feed-in Tariff (FiT) policy: This offers incentive for renewable energy project developers and is one of the policies that the NERC has enacted to assist the integration of renewable energy into the grid. Also, the NERC has created rules for grid connection and net metering, allowing small-scale renewable energy systems to be connected to the grid (IRENA, 2019).
ii. The Nigerian government's National Renewable Energy and Energy Efficiency Policy (NREEEP), which was introduced in 2015, offers a framework for the growth of renewable energy and energy efficiency in Nigeria. The policy identifies strategies for meeting the renewable energy generation targets that are specified (IRENA, 2019). Rules established by the Rural Electrification Agency (REA): The REA has established regulations for the development of projects using off-grid renewable energy in rural regions. These regulations offer project creators help, including funding and technical support (IRENA, 2019).
iii. Tax incentives: To promote the development of renewable energy projects, the Nigerian government may offer tax advantages. Investors can receive tax incentives for renewable energy projects, for instance, in the form of accelerated depreciation or investment tax credits (ITCs) (IRENA, 2019).
iv. Regulations supporting the development and use of smart technologies can be implemented by the Nigerian government. These rules may include connectivity standards, data privacy and cyber security restrictions, and standards for communication protocols (World Bank, 2021). The implementation of this regulation is essential for expansion.

The Nigerian Electricity Regulatory Commission (NERC) has created regulations for smart metering, grid codes, and renewable energy integration (NERC, 2021). Yet, it is important to examine how these restrictions may affect Nigeria's infrastructure expansion and adoption of smart grid technologies. Regulations for data privacy, cybersecurity, and communication protocols are also essential for ensuring the safety and dependability of the smart grid infrastructure. To make sure that they do not prevent the implementation of smart grid technologies, these restrictions must also be examined. Hence, laws are required to direct the implementation of smart grid technologies in Nigeria, but in order to ensure their successful implementation, their effects on the growth of the grid and the acceptance of smart grid technologies may be carefully considered.

2.15 Stakeholders collaboration in ensuring successful integration of renewable energy sources and smart grid technology in Nigeria

The public policy frameworks mentioned above, such as Feed-in Tariffs, Renewable Portfolio Standards, Net Metering, Tax Incentives, and Green Bonds, can be implemented in Nigeria to promote investments in renewable energy infrastructure, support local businesses, and generate employment opportunities. Nigeria's electricity grid system faces various technical challenges, including lack of infrastructure, high transmission losses, and limited access to electricity in some areas. By adopting these policies, Nigeria can address these challenges and transition towards a more sustainable and stable grid network with a higher renewable energy mix. Additionally, policies like these can attract private sector investment, improve the quality of life for communities with limited access to electricity, and promote economic growth. The Nigerian government can work closely with private sector investors, energy providers, and other stakeholders to implement these policies effectively and create a more sustainable energy future for the country.

Nigeria has already put in place a number of laws and policies to encourage the use of smart grid technology and more renewable energy sources. However, more laws and rules need to be put in place, notably those that offer better financial incentives for renewable energy initiatives, encourage the advancement of smart grid technologies, and lower entry barriers for project developers. The government, utilities, regulators, investors, and consumers must work together for the integration of more renewable energy sources and smart grid technology in Nigeria. Every stakeholder has a crucial part to play in making sure that programs for smart grids and renewable energy are implemented successfully. Secondly, the government can support legislative initiatives and regulatory frameworks that encourage the adoption of smart grid and renewable energy technologies. For instance, to stimulate private investment in renewable energy projects, the Nigerian government may provide tax incentives, feed-in tariffs, and other financial incentives. The government can also create rules that guarantee fair and equal access to the grid for producers of renewable energy and facilitate the implementation of smart grid technology. In order to assure the grid integration of renewable energy sources, utilities might work with producers of renewable energy. According to Qu, et al. (2020), utilities can invest in smart grid technology to facilitate the integration of renewable energy sources and boost grid efficiency. Examples of these technologies include enhanced metering infrastructure, distribution automation, and energy storage systems. Thirdly regulators can oversee compliance with laws that support the fusion of smart grid technology with renewable energy sources. Regulators can also set requirements for the production, transmission, and distribution of renewable energy and make sure that all parties involved follow those requirements. Fourthly, money for smart grid initiatives and renewable energy projects can come from investors. In order to foster innovation and bring down prices, investors might also assist research and development in the fields of smart grid technologies and renewable energy.

Finally, by being informed and educated on the advantages of these technologies, consumers may encourage the deployment of renewable energy and smart grid technology. The successful integration of more renewable energy sources and smart grid technology in Nigeria requires the cooperation of numerous stakeholders. Consumers can also take part in demand response programs and modify their energy consumption patterns to support the integration of renewable energy sources into the grid. Stakeholders can build a sustainable energy future for Nigeria that benefits the nation's economy, ecology, and society by cooperating.

3.0 Methodology

The systematic review approach was utilized for this study, to synthesize all available data transparently and repeatedly on the research question. It is a thorough and organized method of reviewing the literature that include finding, analyzing, and synthesizing pertinent papers in order to provide a response to a particular research topic. To provide a thorough and objective overview of the evidence that is currently available on this topic, the systematic review was adopted in conducting the research with the intention of assisting in policy and practice decision-making. Systematic reviews were also used because it can also point out knowledge gaps and suggest areas for further study.

3.1 Research Question

Base on the aim and objective the following research will guide the review:

1. What technology obstacles prevent the inclusion of renewable energy sources into the Nigerian power grid system?
2. How large a renewable energy capacity must be added to the Nigerian grid system in order to attain effective stability?

3. What kind of public policy framework can encourage investments in renewable energy infrastructure, support the growth of local companies, and provide job opportunities?
4. How can Nigeria's grid network employ more renewable energy to cut greenhouse gas emissions in accordance with global efforts to slow down climate change?
5. What are the best practices and procedures for managing a grid to lessen or prevent system collapse, improve grid dependability, increase energy efficiency, and incorporate smart grid solutions, and what is the timeframe for putting these procedures into action over the course of the next five years?

3.2 Research strategy

The following databases were utilized for this systematic review which include Web of Science, Scopus, ScienceDirect, IEEE Xplore, ProQuest. The terminologies utilized
Search Words and Keywords: The following were among the search terms and keywords used in the search: Nigeria, renewable energy, Grid system, smart grid, emissions of greenhouse gases emission, system collapse, Energy efficiency, public policy, technology difficulties. Search as

1. "Nigeria" AND "electricity grid"
2. "renewable energy" AND "Nigeria"
3. "smart grid" AND "Nigeria"
4. "grid stability" AND "Nigeria"
5. "greenhouse gas emissions" AND "Nigeria"

The study selection process for this research will be conducted systematically following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines

3.3 Inclusion and Exclusion Criteria:

To focus the search results, the following inclusion and exclusion criteria were applied:
Inclusion Standards:

- Studies done in Nigeria or pertaining to the country's electricity grid system.
- Studies on energy efficiency, smart grid, renewable energy, and public policy
- Research done between 2010 and 2023
- Studies that were written and published in English

Exclusion Standards:

- Papers that are unrelated to the review's goals or research questions
- research conducted prior to 2010 research conducted in a language other than English
- research done outside of Nigeria
- studies not focused on renewable energy, smart grid solutions and Nigeria electricity grid system

3.4 Screening Procedure:

The following procedures was taken as part of the screening procedure to assess whether studies were eligible to be included in the review.

- Titles and abstracts are screened to find studies that may be relevant using the inclusion and exclusion criteria.
- Full-text screening of the studies that may be pertinent to evaluate whether they qualify for the review based on the study's goals and questions.
- Evaluation of the eligible studies' quality using the Cochrane Risk of Bias tool to assess the reliability and validity of the results.
- Data gathering and compilation from the relevant research that qualify for the review

3.5 Data Synthesis and Extraction

Data extraction comprises the discovery, selection, and analysis of pertinent information from published literature, report, and other pertinent sources because secondary data was employed in this study. The data synthesis process involved the extraction and analysis of relevant data from the selected articles. This helps to ensure that the findings are meaningful and informative. According to Popay, *et al.,* (2006), the data synthesis process should be transparent and systematic. The articles were categorized based on their relevance to the study objectives. Data from each article were extracted and summarized according to the study objectives. Reading through each of the chosen publications and determining the most important conclusions, suggestions, and findings in relation to the study's goals was data extraction.

The thematic approach, which involves categorizing the data in accordance with topics or categories related to the study objectives, was used to organize and analyze the collected data as part of the data synthesis procedure. With the use of this technique, patterns and trends in the data were found, and a thorough understanding of the integration of renewable energy into the Nigerian grid may be developed.

3.6 Quality Assessment

Secondary data was mainly used in this investigation. As a result, the authenticity and dependability of the sources employed will be the main emphasis of the quality assessment, according to McLeod and Wright, (2021). A thorough search of reputable academic databases like Web of Science, Scopus, and Google Scholar will be used to find peer-reviewed articles, books, reports, and other pertinent sources related to the goals of the study as part of the process used to evaluate the quality of the studies that were included.

The relevance of the study to the research question, the caliber and rigor of the research methods employed, the validity and reliability of the data, the accuracy and credibility of the findings, and the standing and reputation of

the authors and publishers was considered when determining the level of evidence for each study.

The search strategy was created to incorporate a varied range of sources from different geographical regions and views to reduce the danger of bias. Only sources that have been rigorously peer-reviewed or that were released by recognized academic publishers, governmental sources and independent report will also be included. The findings of the systematic literature review were reported in a clear and transparent manner, following established reporting guidelines such as PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). This helps to ensure that the review is transparent and reproducible, this study also identifies and discloses any potential conflicts of interest.

4.0 Presentation of findings, interpretation and discussions.

The presentation and interpretation of data acquired from secondary sources including books, journals and internet publications are presented in this chapter and the data will be analyzed using graphs, frequency tables and text. The goal is to find answers to the research questions and realize the study's objectives. The findings and their ramifications are also discussed in this chapter**.**

4.2 Data Analysis

Research question 1: What technology obstacles prevent the inclusion of renewable energy sources into the Nigerian power grid system?

According to a study by the Nigerian Energy Program (NESP) and the United Nations Development Program (UNDP), the lack of grid infrastructure is the most significant technology obstacle with 53% of survey respondents identifying it as a challenge (NESP and UNDP, 2017). Limited storage capacity ranked second with 24% of respondents identifying it as an obstacle, while outdated grid technology ranked third with 16% of respondents (NESP and UNDP, 2017). The inadequate metering and billing system ranked fourth with 5% of respondents and limited human capacity ranked last, with only 2% of respondents (NESP and UNDP, 2017). This ranking is shown in Figure 1.

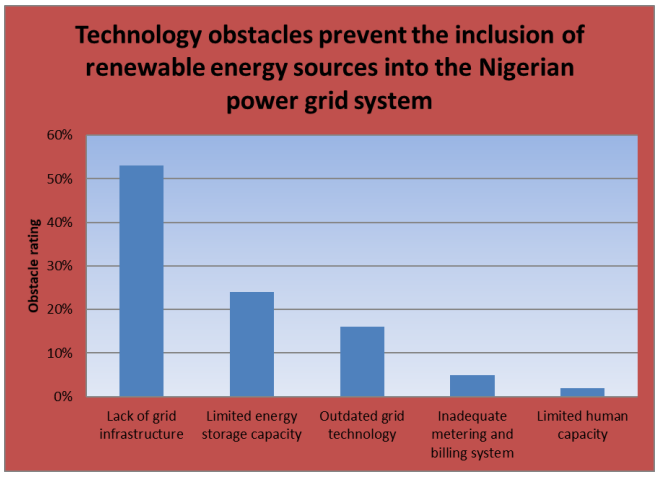

Figure 1: Chart showing ratings of technological obstacles preventing the inclusion of renewable energy sources into the Nigerian power grid system.

Interpretation of Findings

The study conducted by NESP and UNDP sheds light on the technological challenges that Nigeria's power grid system faces in integrating renewable energy sources. The biggest issue is a lack of grid infrastructure, which can be solved by investing money on substations and transmission lines to assist renewable energy sources (NESP and UNDP, 2017). Another challenge that can be overcome is a lack of energy storage capacity, which can be overcome by developing energy storage technologies such batteries and pumped hydro storage (NESP and UNDP, 2017). The electricity grid system can be updated with contemporary technology, such as smart grid technologies, to address out-of-date grid technology (NESP and UNDP, 2017).

Additionally, a dependable metering and billing system can be implemented to address the insufficient system, which can boost earnings and stimulate investment in renewable energy (NESP and UNDP, 2017). Lastly, the Nigerian power sector may address its limited human capacity by investing in the education and training of qualified workers.

Overall, the study's aim of recommending a sustainable solution that will bring about efficient stability in Nigeria's grid network with a greater mix of renewable energy sources while also addressing other technical challenges faced by the Nigerian electricity grid system can be achieved with the help of the recommendations based on the findings of the NESP and UNDP study.

Research question 2: How large a renewable energy capacity must be added to the Nigerian grid system in order to attain effective stability?

Presentation of data

Table 3: Power Generation Sources in Nigeria

Power generation sources	Installed capacity (MW)
Gas- fired power plants	11,580
Grid- connected renewable	1447
Other sources	400
Total	13,427

Note: "Other sources" include sources such as coal and diesel. Source: Nigerian Electricity Regulatory Commission (NERC), 2021. The Nigerian Electricity Regulatory Commission (NERC) estimates that as of 2021, Nigeria's installed capacity for power generation is roughly 13,427 megawatts (MW), with about 1,447 MW coming from grid-connected renewable energy (NERC, 2021). This includes contributions from renewable energy sources including solar, biomass, and hydropower. However, gas-fired power plants still make up around 86% of all installed capacity in Nigeria, where the majority of the country's electricity is still produced using fossil fuels (NERC, 2021).

Table 4: Renewable Energy Capacity targets in Nigeria

Renewable Energy Capacity Targets in Nigeria	GW
Total installed capacity (2030 target)	**30**
Grid- connected renewable energy (2030 target)	**13.8**
Grid- connected renewable energy (excluding hydropower) (2030 target)	**9.1**

Source: Federal Ministry of Power, Works and Housing (2018); NERC (2021).

According to the Nigerian government's capacity expansion target. A total of 13.8 GW of grid-connected renewable energy capacity needs to be added to the Nigerian grid system in order to attain effective stability by 2030(Federal Ministry of Power, Works and Housing, 2018). This represents 45% of the total installed capacity target of 30GW. However, this figure includes medium and large hydropower and when excluding them, the grid-connected renewable energy capacity target is 9.1 GW or 30% of the total installed capacity target (Federal Ministry of Power, Works and Housing, 2018). This is shown in the frequency table below.

Interpretation of Findings

In accordance with the data, Nigeria's installed capacity for grid-connected renewable energy is currently quite low, making up only around 10.8% of all installed capacity as of 2021 (NERC, 2021). In order to reach the government's goal of 30GW installed on-grid capacity by 2030, it is clear that renewable energy capacity must be significantly increased. According to the Federal Ministry of Power, Works, and Housing (2018), grid-connected renewable energy accounts for 13.8 GW or 45% of total generation and 9.1 GW or 30% when medium and large hydro powers is excluded.

It will be necessary to concentrate on boosting the capacity of grid-connected renewable energy sources through the development of policies and incentives to encourage investment in the sector in order to accomplish this research aim of recommending a sustainable solution that will usher in efficient stability in Nigeria's grid network with a more renewable energy mix, while addressing other technical challenges. Some of these policies are discussed in research question three below. It may also be necessary to address technical challenges such as the lack of grid infrastructure, limited energy storage capacity, and outdated grid technology, which were identified as key obstacles in a study by the Nigerian Energy Support Program and the United Nations Development Program (NESP and UNDP, 2017).

Research question: What kind of public policies can encourage investments in renewable energy infrastructure, support the growth of local companies, and provide job opportunities?

Research Findings

Public policy frameworks that can promote investments in infrastructure for renewable energy, aid small enterprises in the area, and generate employment prospects include:

Feed-in tariffs (FITs) is a public policy framework that can promote investments in renewable energy infrastructure, foster the expansion of regional businesses, and provide job opportunities. FITs are regulations that promise set prices to producers of renewable energy for the electricity they create and feed into the grid. This gives producers of renewable energy a steady source of income and encourages investment in renewable energy infrastructure. Additionally, FITs may stipulate that a specific proportion of renewable energy must be produced domestically, fostering the expansion of regional businesses, and generating employment possibilities (Aznar, *et al.,* 2017).

Renewable Portfolio Standards (RPS): RPS is a regulatory framework requiring utilities to produce a certain percentage of their electricity from renewable energy sources. RPS can encourage the development of the renewable energy industry, advance technology, and open up job opportunities (Wiser & Barbose, 2008).

Net metering: Net metering is a legal framework that enables users to resell any extra electricity they produce from renewable sources to the grid. Customers will have a financial incentive to invest in renewable energy infrastructure, which will help local businesses thrive (Alderfer, *et al.,* 2017).

Tax Incentives: Tax benefits like Production Tax Credits (PTCs) and Investment Tax Credits (ITCs) can lower the cost of renewable energy projects and promote investment in the sector. Incentives like these can help local firms expand and provide employment (Friedman, 2016).

Green Bonds: Issued as fixed-income securities to finance ecologically beneficial initiatives, green bonds are another option. This might promote investment in infrastructure for renewable energy sources, assist neighbourhood businesses, and create job possibilities (Brinkman & Simonsen, 2018).

Interpretation of Findings

By promoting investment in renewable energy infrastructure, assisting local businesses, and generating employment opportunities, the introduction of feed-in tariffs (FITs) and other policies can be a viable solution to Nigeria's grid network problems. According to the Federal Ministry of Power, Works, and Housing, (2018), Nigeria may use this regulatory framework to meet its capacity expansion goal of 30 GW of installed on-grid capacity by 2030, with grid-connected renewable energy accounting for 13.8 GW (45% of generation).

Feed-in Tariffs, Renewable Portfolio Standards, Net Metering, Tax Incentives, and Green Bonds are a few examples of public policy frameworks that can be implemented in Nigeria to encourage investments in renewable energy infrastructure, support local businesses, and create job opportunities. Numerous technical issues, such as a lack of infrastructure, high transmission losses, and restricted access to electricity in some areas, face Nigeria's electricity grid system. Nigeria may address these issues and move towards a more sustainable and reliable grid network with a higher proportion of renewable energy by implementing these policies. These kinds of regulations can also encourage private investment, enhance the standard of living in areas with poor access to energy, and advance economic development.

To effectively implement these policies and build a more sustainable energy future for the nation, the Nigerian government can collaborate closely with private sector investors, energy suppliers, and other stakeholders.

Research question 4

How can Nigeria's grid network employ more renewable energy to cut greenhouse gas emissions in accordance with global efforts to slow down climate change?

Research Findings

According to a report by the International Energy Agency (IEA), Nigeria's energy demand is expected to triple by 2040 (IEA, 2019). This increase in demand makes it essential for Nigeria to focus on renewable energy sources to meet its energy needs while reducing greenhouse gas emissions. To achieve this goal, the government has introduced policies and incentives to encourage the development of renewable energy, including the Nigerian Electricity Regulatory Commission's feed-in tariff system and the establishment of the Nigerian Bulk Electricity Trading Company to purchase electricity from renewable energy producers (Federal Ministry of Power, 2015), net metering, and tax incentives, which give renewable energy producers a steady source of income and support the financial viability of renewable energy projects (IRENA, 2020).

By establishing public-private partnerships and giving local businesses the chance to take part in renewable energy projects, another option is to encourage private sector investment in renewable energy (IRENA, 2020). Private sector investment is also crucial for the growth of renewable energy in Nigeria. According to a report by the World Bank, Nigeria's private sector investment in renewable energy has been increasing, with investments totaling over $2 billion between 2010 and 2017 (World Bank, 2019). To further encourage private sector investment, the Nigerian government has established the Nigerian Renewable Energy and Energy Efficiency Fund to provide financial support to renewable energy projects (Federal Ministry of Power, 2015).

Nigeria can also look into ways to use more renewable energy in industries that contribute significantly to greenhouse gas emissions, such transportation and agriculture. In order to reduce emissions and increase demand for renewable energy, for instance, sustainable farming methods and the marketing of electric vehicles can both be implemented (IRENA, 2020).

In order to promote the use of renewable energy in Nigeria's grid network and lower greenhouse gas emissions in line with international efforts to combat climate change, a multifaceted strategy is required.

Interpretation of Findings

The implementation of a multifaceted strategy that promotes the use of renewable energy and lowers greenhouse gas emissions in Nigeria's grid network can help achieve the research goal of recommending a sustainable solution to achieve efficient stability in Nigeria's grid network with a more renewable energy mix while addressing technical challenges. This can be accomplished, in accordance with IRENA, (2020), by creating a supportive regulatory environment, implementing policies that support the development of renewable energy, such as feed-in tariffs, net metering, and tax incentives, encouraging private sector investment in renewable energy, and looking into opportunities to increase the use of renewable energy in sectors that significantly contribute to greenhouse gas emissions. Nigeria's grid network can provide effective stability, lower greenhouse gas emissions, and promote sustainable development by implementing these measures.

Research question 5: What are the best practices and procedures for managing a grid to lessen or prevent system collapse, improve grid dependability, increase energy efficiency, and incorporate smart grid solutions, and what is the timeframe for putting these procedures into action over the course of the next five years?

Research Findings

The following are instances of best practices and processes for managing a grid to avoid system failure, increase

dependability, boost energy efficiency, and implement smart grid solutions:

1. Ensuring the grid infrastructure's dependability and safety by performing routine maintenance and improvements (Xue et al., 2020): Making ensuring that the grid infrastructure is continuously maintained and enhanced is one of the main ways to avoid system collapse and boost grid dependability. This calls for a variety of actions, such as system updates, equipment replacements, and standard maintenance jobs like vegetation control and system testing. Operators can find and address problems before they become serious ones by engaging in such operations. For instance, according to Xue et al. (2020), routine equipment inspections and maintenance can assist identify problems like worn-out or broken components that could eventually lead to system failures.

2. Demand response programs are being used to balance electricity supply and demand to prevent grid overload (Khan, *et al.,* 2018): Programmes for demand response (DR) have become an essential tool for grid management, especially during times of high demand. When power demand is high, these programmes encourage users to use less of it, balancing supply and demand and preventing grid overload. Khan, *et al.,* (2018) claim that DR programmes can lower peak demand by up to 20%, reducing the chance of a systemic failure. However, in order for DR programs to be successful, they must be well-thought-out, well-funded, and supported by smart grid technologies that enable real-time power flow monitoring and control.

3. To enhance grid monitoring, control, and management, advanced metering infrastructure (AMI) and other smart grid technologies are being installed (Xue et al., 2020): In order to improve grid monitoring, control, and management, smart grid technologies like advanced metering infrastructure (AMI) and supervisory control and data acquisition (SCADA) systems are essential. Real-time monitoring of energy use at the customer level is made possible with AMI, enabling precise load balancing and demand forecasting. While this is going on, SCADA systems provide remote monitoring and control of grid components, giving operator's access into the health of the grid and allowing them to react swiftly to system outages. According to Xue, *et al.,* (2020), the implementation of such smart grid technology is essential for the stability and dependability of the grid.
4. Improving grid efficiency and reducing reliance on fossil fuels by increasing the usage of renewable energy sources and energy storage devices (Khan, *et al*., 2018): Moving towards renewable energy sources like solar and wind power is one strategy to promote grid sustainability and efficiency. These sources are a desirable substitute for fossil fuels since they are affordable, plentiful, and generate no greenhouse gases. Batteries and other energy storage technologies can also lessen the intermittent character of renewable energy sources and provide grid operators more control over how power flows. However, large infrastructure and policy support investments are necessary for the deployment of renewable energy sources and energy storage technologies. The cost of renewable energy technologies has significantly decreased recently, making them more competitive with conventional sources, claim Khan et al. (2018). Therefore, there is a chance for policymakers to encourage their adoption through encouraging regulations and policies
5. Creating response strategies and contingency plans to deal with unforeseen situations, including equipment failure, cyberattacks, and harsh weather (Xue, *et al.,* 2020): Despite taking precautions to avoid system failure, unforeseen circumstances can still happen and interfere with grid operations. To lessen the effects of the disruption in such situations, it is essential to have reaction tactics and contingency plans in place. Such preparations can entail restoring electricity as soon as possible, putting backup power systems in place, and interacting with clients and stakeholders to give updates and direction. Response methods and emergency plans are essential for improving grid resilience and lowering the risk of system collapse during unforeseen events claim by Xue, *et al.,* (2020).

Interpretation of findings

This information gives important insights into how to manage a grid in the best possible ways to avoid system failure, improve dependability, increase energy efficiency, and implement smart grid technologies. These processes can be used to improve the stability and sustainability of the Nigerian power grid system, as well as to address technical issues and use more renewable energy sources.

According to the report, regular maintenance and upgrades to the grid infrastructure should be made to guarantee dependability and safety. To further enhance grid monitoring, control, and management, advanced metering infrastructure (AMI), demand response programs, and other smart grid technologies can be deployed. In addition, expanding the use of energy storage technologies and renewable energy sources can enhance grid performance and lessen the reliance on fossil fuels.

These suggestions can be used as a springboard for the creation of a long-term fix to increase the proportion of renewable energy sources in Nigeria's grid network and increase grid stability. The right schedule for carrying out

these operations can be created by looking at the grid's current state, the resources at hand, and the goals of the grid operator.

3. CONCLUSIONS

This research sought to identify long-term strategies that would support effective stability in Nigeria's grid network, combining a greater proportion of renewable energy sources and solving other technical issues the country's power grid system was currently confronting. The results show that Nigeria's electricity sector is dealing with serious issues, such as a dependency on fossil fuels, frequent power outages, inadequate energy production and distribution facilities, and excessive energy costs. In order to ensure the nation's energy security and sustainable development, urgent action must be taken.

According to this study, Nigeria possesses a wealth of renewable energy resources, such as solar, wind, hydro, and biomass, which might be used to diversify the nation's energy supply. Additionally, Nigeria needs to establish favourable regulatory frameworks that would encourage the development of renewable energy. This might be done by implementing policies like feed-in tariffs, net metering, and tax incentives. Another successful tactic could be to provide local businesses the possibility to engage in renewable energy projects and to promote private sector investment in renewable energy through public-private partnerships.

Several best practices and processes, such as routine maintenance and enhancements, demand response programs, advanced metering infrastructure (AMI), renewable energy sources, and energy storage devices should be implemented in order to guarantee grid stability and increase energy efficiency. Nigeria must also have response plans and backup procedures to handle unanticipated circumstances like equipment failure, cyber-attacks, and bad weather.

In order to achieve energy security, sustainable development, and climate change mitigation, the Nigerian government must priorities the promotion of renewable energy sources and the adoption of best practices and guidelines. These solutions will need a lot of money and political will to be put into place, but over time they will have a huge positive impact on the economy and the environment.

Overall, the suggestions made in this study are essential for Nigeria to construct a strong and sustainable energy infrastructure that can offer its inhabitants dependable, inexpensive and sustainable energy while fostering economic growth and reducing climate change. Policymakers, grid operators, investors, and other stakeholders are urged to priorities implementing these solutions in order to aid Nigeria's transition to a sustainable energy future by reading this research.

4. Recommendations

Recommendations

Based on the study's findings, the following recommendations are made:

i. The study discovered that Nigeria's reliance on fossil fuels for electricity generation is a substantial contributor to greenhouse gas emissions and other environmental issues. It therefore recommends increasing the usage of renewable energy sources. Therefore, in order to lower the nation's carbon footprint and improve the sustainability of its energy system, there is a need to increase the usage of renewable energy sources like solar, wind, and hydropower.

ii. The study showed that one of the main issues Nigeria's energy system is facing is a lack of suitable grid infrastructure. In order to increase the grid's dependability and efficiency, it is necessary to engage in modernization and expansion projects.

iii. Implement smart grid technologies: According to the study, demand response Programmes and advanced metering infrastructure (AMI) can considerably enhance grid management and lower the likelihood of system failure. Therefore, it is necessary to integrate these technologies into Nigeria's electrical infrastructure.

iv. Promote private sector investment: The study discovered that private sector investment may play a critical role in fostering the growth of renewable energy projects and enhancing the grid infrastructure. Therefore, it is necessary to enact policies like feed-in tariffs, tax incentives, and public-private partnerships in order to foster a climate that is favorable for private sector investment.

v. Improve cooperation and coordination: The study revealed that cooperation and coordination between electrical sector players are essential to the development of a sustainable energy system. In order to improve collaboration and coordination among stakeholders, including governmental organizations, grid operators, producers of renewable energy, and consumers, it is necessary.

vi. Boosting public participation and knowledge was found to be crucial for encouraging the use of renewable energy sources and boosting the sustainability of the power system. As a result, there is a need to raise public awareness through educational and outreach initiatives and to promote public participation through laws like net metering and initiatives for locally sourced renewable energy.

vii. By putting these suggestions into practice, Nigeria may create an electricity system that is dependable and sustainable, supports economic growth, and addresses environmental issues. Also, more research should be carried out in the area

sustaining applying these technology and renewable energy in smaller units to power homes.

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