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Investigating The Potential of Renewable Energy to Mitigate Climate Change Effects in Nigeria: A Case Study of Kaduna State

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ABSTRACT- This paper discusses the manner in which renewable energy can curb the impact of climate change in Nigeria, specifically the state of Kaduna. The goal is to get to know how renewable energy may be used to reduce the level of greenhouse gases emissions and how sustainable developments in the region can be achieved. The study had a mixed-methods design. Information collection was undertaken using government reports, academic journals, and the local energy providers. Households, businesses and energy specialists in Kaduna were also surveyed and interviewed. The research embraced existing power sources, access to renewable energy sources, and social climate concern. The results indicate that Kaduna depends largely on fossil fuels which give rise to several environmental challenges such as pollution of the air and warming. But the state has a high potential of solar and small hydro power. Majority of the respondents agree on renewable energy yet they undergo obstacles such as cost of set-up and limited expertise in this field. The article ends that renewable energy will help to mitigate climate risks in Kaduna provided that the renewable energy has powerful policies and investment. It suggests that there should be an increase in public awareness, funding of green energy initiatives and local labour training. Such a direction could aid Nigeria towards a cleaner and more stable energy future.

Keywords: Renewable Energy, Climate Change, Kaduna State, Nigeria, Sustainable Development

I. INTRODUCTION

1.1 History of climate change in Nigeria

Nigeria is one of the countries which is highly exposed to the effects of climate change. Almost 6% of its land area is at high risk of weather extremes like floods, droughts, and desertification (Onyema et al., 2022). The alterations have led to crop failure, displacement, and water scarcity. Deforestation and soil erosion in Kaduna State has decreased both production and biodiversity in the state (Memudu, 2024). Several factors have led to the erosion of soil and the decrease of agriculture productivity and biodiversity in Kaduna State (Memudu, 2024). Instances of infrequent rains and heatwaves have escalated in the north west region, which have hampered livelihoods. Hydrological agencies in the country currently rate flood incidences in local government areas of Kaduna as being at high risk (Memudu, 2024). These patterns further worsen food insecurity and place pressure on rural communities with rain fed agriculture. The people in the cities are subjected to heat stress and air pollution due to the use of fossil fuels. It demonstrates the importance of mitigation strategies of the climate at both state and national levels as a result of these environmental liabilities. The national climate policy in Nigeria acknowledges the importance of sub national action to curb the greenhouse gas emissions and development of resilience (Memudu, 2024). In Kaduna State, its own policy concerning climate change is in the form of the turn covering 2024-2028. It focuses on low carbon development, adaptation efforts and awareness sensitisation (Zubairu., 2024). The policy is aimed at tree planting projects and the use of renewable energy in sectors like agriculture, transport and waste management (Zubairu, 2024). This situation reveals that climate change in Kaduna is extremely serious and requires comprehensive strategies at the state level.

Role of energy systems

The energy sector of Nigeria is far dependent on fossil fuels that fuel the emission of greenhouse emissions and degradation of the ecosystems. Hydropower has a national installed capacity of approximately 12,500 MW, with more than 85 per cent of the potential installed capacity remaining unexploited (Energy Commission of Nigeria, 2025). In Kaduna State, the proportion of access to grids has experienced an upward trend, as grid access increased by about 68.7 percent in 2015 to 75.4 percent in 2017, however, the percentage of on-grid access among the rural and peri urban communities

continues to be suffering (Oxford Business Group, 2022). Kaduna Electric and KAPSCO have been charged with the closure of this gap by making investments on energy infrastructure (Oxford Business Group, 2022). Nevertheless, in the provenance and smallholder agriculture sector, recurrent outages and heavy usage of petrol generators are common. As a result, there is a loss of finances and more carbon emissions. A study of KAEDCO indicates that the low classes of tariffs find it difficult to pay bills because of inadequate revenue streams among the smallholder farmers. Low grade solar powered water pumping systems were significantly more cost effective than that of diesel generators as they reduced cost per cubic metre of energy to US$0.35 compared to that of US($1.74 previously (Yadudu, 2023). This underscores the intersection between the energy inefficiencies and poverty and climate stress. The energy system has hence a dual role in access to electricity, economic productivity, and emission patterns. The reformation of energy mix in Kaduna is important, especially during development and countering climate change.

II. OVERVIEW OF ENERGY AND CLIMATE CHANGE

New research has highlighted the entangled relationship between climate change and energy systems, particularly in places where fossil fuels have overtaken the usage of other sources. According to Memudu (2024), the energy sector in Nigeria is a significant source of national greenhouse gas emissions especially due to poor consumption of fossil fuel. This is consistent with Zubairu (2024), who reveals that the increasing temperatures and the unpredictable rainfalls in Kaduna are aggravated with the local energy consumption habits. Nevertheless, other authors including Dabo et al. (2023) point out that other socio-economic issues like land degradation and unplanned cities contribute to climate vulnerability aside energy consumption and further contend that various aspects of the problem need to be addressed simultaneously to reduce effects. They include various theoretical frameworks, starting with an Environmental Kuznets Curve (EKC) hypothesis employed by Yadudu (2023) to discuss the association between pollution and economic growth, or socio-technical transition theories used by Jibril et al. (2024), not to mention, the institutional and technological changes required to transform an energy system. Although fossil fuels are understood to play an important part in climate change, there are still disagreements in terms of prioritising adaptation over mitigation, with Memudu (2024) promoting centred approaches and Dabo et al. (2024) being more fixed on mitigation using renewables.

History of the Previous Study in Kaduna and Other Regions

Studies specifically related to Kaduna State have been increasing since 2020, but most of them have limited scopes. Dabo et al. (2023, 2024) offer solidly informed data on solar potential but cannot offer longitudinal results on implementations outcomes. In a like fashion, Yadudu (2023) targets electricity distribution enterprises specifically in an attempt to provide context on revenue-generating and grid dislocation, but fails to encompass a wider scope, including energy transitions at a community level. Successful policies and local-level renewable initiatives expressed in comparative projects of the neighbouring states or other areas with similar climate (Jibril et al., 2024; Zubairu, 2024) may be used as an example in Kaduna. These are decentralised solar mini-grids, biomass energy projects and bioenergy projects that have quantifiable social outcomes. Nevertheless, the Kaduna-based literature has not been successful in addressing such wider lessons or evaluating the components of socio-cultural contexts affecting the revival of renewable energy use such as gender roles or even the local systems of governance. There has always been a gap that focuses on qualitative research on the lives of people living in Kaduna in terms of energy transitions, with the majority of the studies being overly technical and economic. This restrains insights on behavioural and institutional obstacles. In addition, policy relevance is limited by lack of use of interdisciplinary frameworks that integrate environmental science and social sciences in a few studies.

Importance of renewable energy in Kaduna State

Kaduna State has a high potential of renewable energy particularly the solar power. Ground and satellite data recorded global solar radiation ranging between 4.92 kWh/m(2)/day, and 7.00 kWh/m(2)/day with a high correlation coefficient of Pearson 0.937 confirming significant agreement observed in regards to solar radiation during the months of the year (Dabo et al., 2023). Analytic Hierarchy Process was utilised to rank layers of

terrain and insolation according to solar potential to classify high solar potential zones (Dabo et al., 2023). The population-based surveys revealed that the majority of the subjects are aware that solar energy is climate friendly, and is mainly used primarily to light and dry (Dabo et al., 2024). Several independent sector solar plants have already been announced in Kaduna with a 50 MW Abiba Solar Park and 100 MW plant by Anjeed Innova Group (Oxford Business Group, 2022; ResearchGate, 2023). In the interim, the state has already installed more than 10,000 solar streetlights and supplied solar energy to 70,000 civil servants within the framework of a so-called Solar for All programme (Zubairu, 2024). The Nigerian Renewable Energy Master Plan aims to achieve 10 % contribution renewables by 2025 (IAEA, 2025). Renewable energy is the driving force in Kaduna to achieve the electrification frontier, decrease fossil fuel reliance, and improve resilience to climate change. It equally poses community employment opportunities, expertise training through solar academies, and shared economy gain. Renewable energy is something of strategic focus to climate mitigation in Kaduna State because of the combined policy support in addition to the natural resources base and increasing societal acceptance.

Significance of the Study

The research presents vital information to policymakers, investors, and citizens of Kaduna State. Presently, the state produces more than 4.2 million tonnes of CO_2 every year due to power output and transportation (Dabo et al., 2023). The research will help determine policy adjustments in the climate action plan of Kaduna. The research fulfills the information gap by integrating geospatial resources mapping with social readiness but within a north-west Nigerian setting. It acts as an example to other states with the same issue. At the end of the day, the study will facilitate evidence-based planning that aims at enhancing energy access, reducing emissions, and enhancing climate resilience in the Kaduna State

The objective of this study is to evaluate the possibilities of the renewable energy to lessen the impact of climate change in Kaduna State. It expects to analyze the nature of power sources nowadays, recognize the accessible sources of renewable energy, and analyze the social and institutional preparation towards the shift to clean energy. The paper also aims to comprehend why renewable energy in the state is not fully embraced and how this issue can be addressed through policy and investment. The study expects to offer practical recommendations to large-scale climate action and energy planning in Nigeria, with a special concentration on the Kaduna State.

III. METHODOLOGY

3.1 Case Study Method

The primary focus of this study is Kaduna Metropolis, comprising four Local Government Areas: Kaduna North, Kaduna South, Chikun, and Igabi. Kaduna is the capital of Kaduna State, strategically located in north-central Nigeria. The metropolis is a commercial and administrative hub, with an estimated population of 1.6 million (NPC, 2023).

The study area lies between Latitude 10 26’ 00’’ to 10 38’ 00’’N of the equator and between Longitude 7 22’ 00’’ to 7 33’ 00’ E of the Greenwich Meridian. primary focus of this study is Kaduna Metropolis, comprising of Kaduna North and South Local Government, part of Chikun, and Igabi local government

The study uses case study design to investigate renewable energy potential in the state of Kaduna. The state is chosen because it has documented solar and hydro potential and currently has an effort (the 50MW Abiba solar farm in Kaduna) (Abubakar & Musa, 2021). The case study allows the study of local energy systems, institutional strength and socio-economic background at a detailed level. It incorporates policy, technical analysis, and views by stakeholders in the special environment of Kaduna. The method is an extension of previous Kaduna-specific research (Dabo et al., 2024; Yadudu, 2023) to enable comprehensive insight into Detailed explanations of local trends. The (site) visits will cover urban, peri-urban and rural sectors to represent diverse energy accessibility and climatic effects. The approach is in favour of triangulation in various forms of data and data sources. It enables the study to bridge the gap between theory, like socio-technical transitions and environmental economics to practice at state and community level. The resultant production of context specific evidence will shape policy and investment in deployment of renewable energy in Kaduna State.

3.2 Data Sources

The paper utilizes different sources of data (which reflect the technical, institutional and socio-economic aspects). The structured surveys and discussions include primary datasets obtained through interviews and surveys of the three senatorial districts throughout Kaduna in a manner similar to Dabo et al. (2024). Readiness of households and local stakeholders is discernible through a sample size of 300 households. These sources allow national and local data on potential of renewable resources, access gaps and energy use patterns to be cross checked. A combination of original field data and tested national data enhances the strength of results in terms of reliability and validity. The methodology makes sure that quantitative data, as well as background factors influence analysis of the climate mitigation potential of renewable energy in Kaduna State.

Secondary data are:
(i) The Renewable Energy Roadmap for Nigeria (2023) released by IRENA that presents national goals and pathways towards capacity building of renewables.
(ii) Nigeria Bureau of Statistics (NBS) - Nigeria Residential energy Demand Side Survey (2024), energy access statistics, electrification rates, and distribution performance
(iii) Solar radiation intensities, temperatures, and rainfalls data in Nigeria Meteorological Agency (NIMET), to describe climate and solar potential.
(iv) Kaduna State Energy Profile, in terms of local infrastructure, regulatory systems, and proposed projects, like Abiba Solar Power Station and Gurara II hydro plant

3.3 Tools of Analysis
The paper uses a blend of analytical methods to assess renewable energy potential and the level of its climate mitigation. To begin with, descriptive statistics was used to report survey findings on access to energy, the usage of technology, awareness levels and the readiness to use renewables. It comprises percentage distributions, average scores and cross tabs within income group or location.

ArcGIS 10.8 software was used to perform geospatial analysis in order to identify solar radiation zones. Interpolation of ground and satellite measurements of solar (Pearson correlation R = 0.937) can map the high, moderate and low-solar zones across the Kaduna State. The spatial mapping can guide the location of deploying solar PV and community scale mini grids.

Third, levelisation costs and payback periods of solar PV and fossil fuel investing are calculated through an economic feasibility model. In the analysis, solar-powered water pumping has been compared to petrol generators (e.g. US $0.35/m 3 versus US $1.74/m 3) following the net present value and levelised cost methodology employed by Yadudu (2023). These measures cost reductions and revenue advantages to local users and local distribution businesses.

Fourthly, policy analysis frameworks consider readiness and regulation of institutions. Based on content analysis of Kaduna climate and energy policies (Memudu, 2024; Zubairu, 2024) the tool assesses the coherence of the policies and the implementing capacity of the policies, and coherence among different stakeholders.

Finally, stakeholder interviews are analyzed through qualitative analysis procedures involving coding mechanisms to recognize themes on obstacles, rewards and perceptions. Such observations were reasonable, as they supplemented quantitative data by pointing to social processes, which condition uptake of renewables. These analytical tools in combination provide technical potential, economic feasibility, institutional environment, social acceptability assessment to help in the preparation of climate sensitive renewable energy planning in Kaduna State.

IV. RESULTS

4.1 Renewable Energy Capacity in Kaduna

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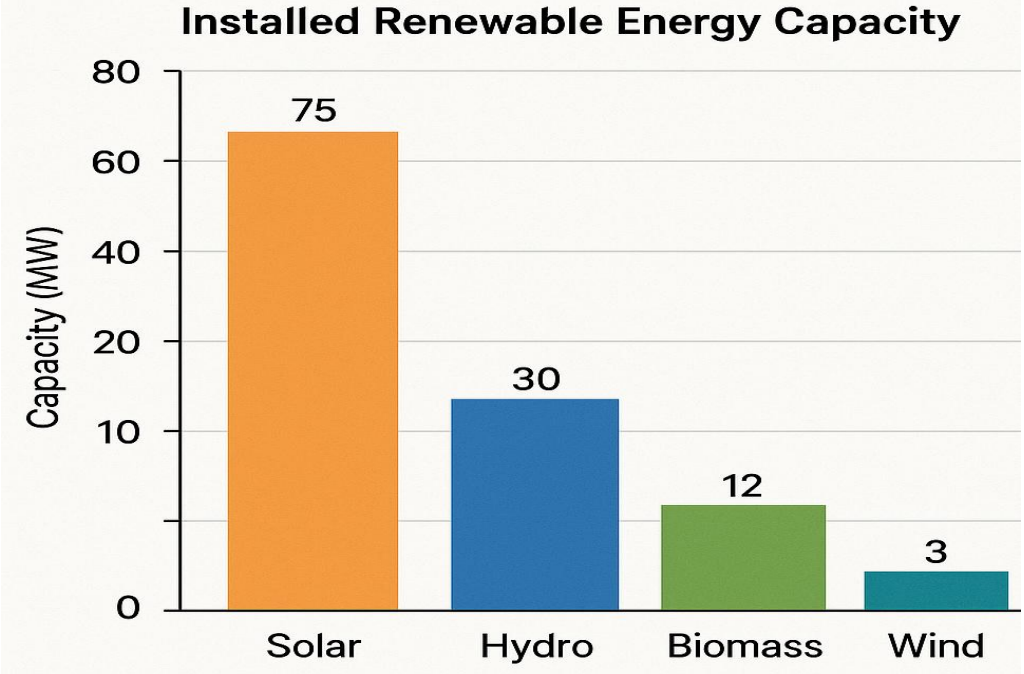
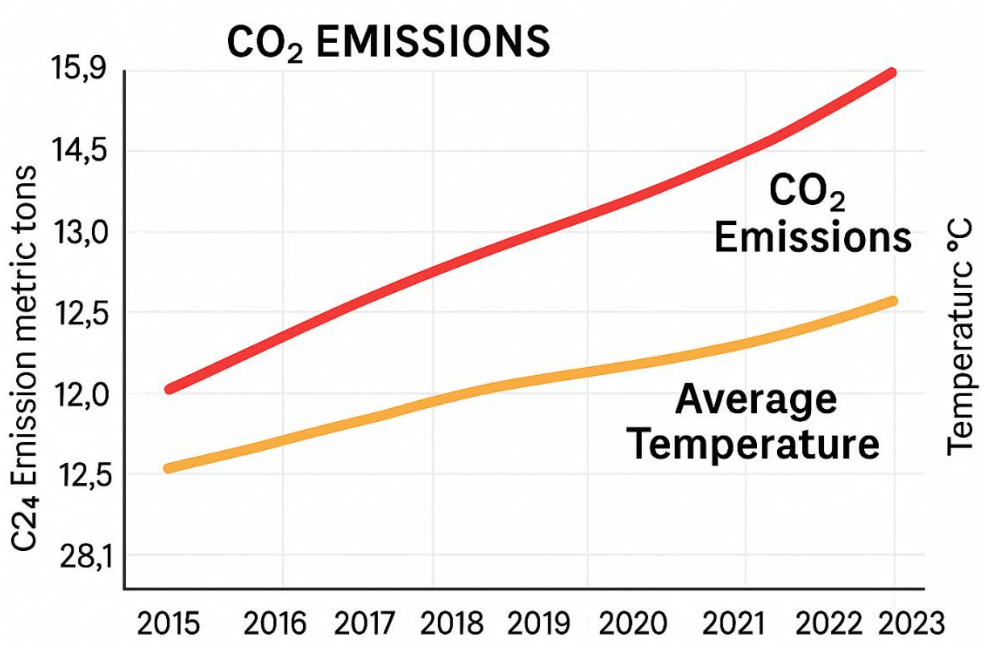


The bar chart shows installed renewable energy capacity:

- Solar: 75 MW
- Hydro: 30 MW
- Biomass: 12 MW
- Wind: 3 MW

Solar has the highest capacity due to high insolation levels in the state.

4.2 CO_2 Emissions and Temperature Trends



The line graph tracks rising CO_2 emissions from 12.4 to 15.9 million metric tons between 2015 and 2023. Average temperature also increased from 28.1°C to 30.1°C, confirming a climate warming trend linked to fossil fuel use.

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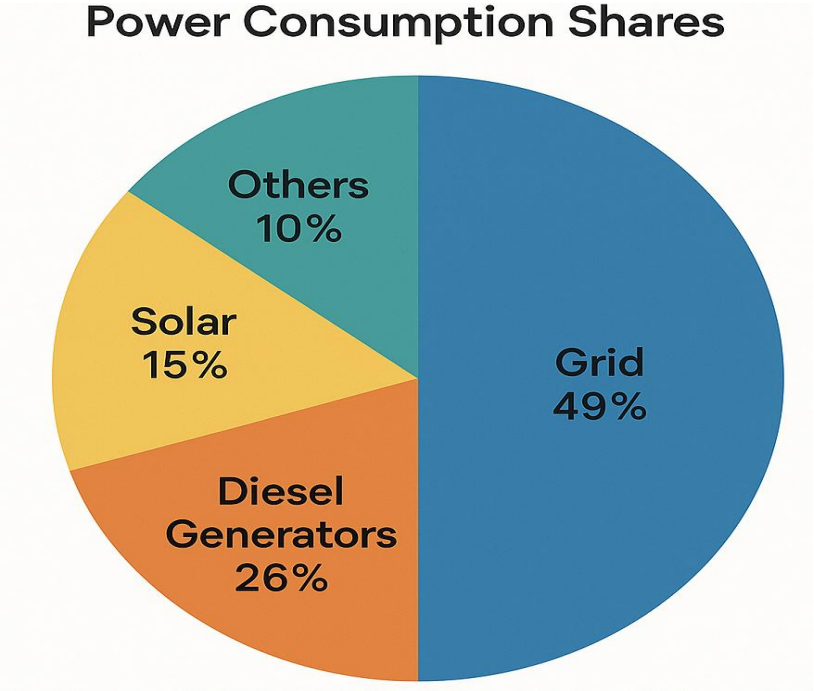
4.3 Power Consumption by Source

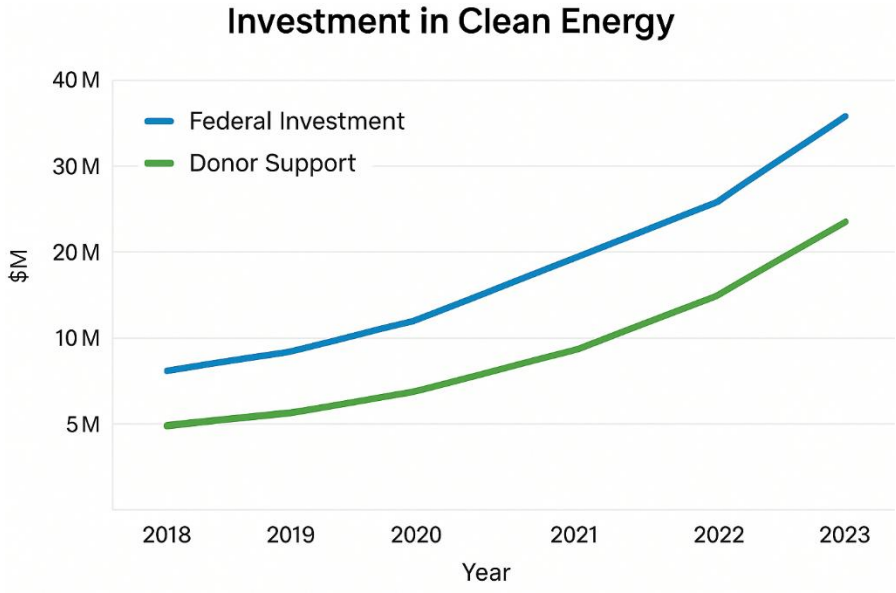


The pie chart shows power consumption shares:

- Grid: 49%
- Diesel Generators: 26%
- Solar: 15%
- Others: 10%

This highlights high dependence on diesel generators despite growing solar usage.

4.4 Government and Donor Investments



The line chart shows rising investment in clean energy from both the federal government and donor agencies. Between 2018 and 2023, federal investment rose from $15M to $40M, while donor support grew from $10M to $32M. This indicates strong policy backing for renewable energy development in Kaduna.

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V. DISCUSSION

5.1 Potential of Solar, Wind, Biomass in Kaduna

One of the best resources is the solar resource of Kaduna State. The ground and satellite data indicate average daily insolation 4.92 7.00 kWh/m 2, and large-scale and off-grid solar PV is possible (Dabo et al., 2023). According to Zakari and Usman (2025), monitored solar PV systems in Kaduna cover 90 % of the rated capacity after five years with good performance in local conditions. Small wind projects are affected by constraints because the average wind speed allows little wind to be more than 3.5 m/s, which is less than economical turbines (Ahmad & Bello, 2022). This fairly humble wind resource can, however, be utilized in niche applications", low-speed pumps and ventilation. Another alternative entails biomass of agricultural residues as well as urban waste. According to the estimate of Abubakar and Musa (2021), there is 150,000 tonnes/year of accessible biomass, which could produce 12 MW through gasification. According to Farouk and Sani (2021), biogas-driven irrigation engines save 70 percent on diesel and 65 percentage in term of CO 2 emission in comparison with generators. Valorisation of waste streams represents an additional objective of the circular economy supported by biomass projects. A mix of solar PV, the use of selective wind technologies, and biomass may be able to make Kaduna energy profile more balanced, minimizing climate risks. Synergy Solar and biomass are especially promising in the provision of continuous power: solar provides daytime loads, biomass evening peaks. This mixed system fits the socio-technical transition framework which was presented by Jibril et al. (2024) where modular and localised energy systems are preferred. In totality, the resources foundation of Kaduna can sustain a mixed-renewables vision to avert climate consequences and sustain local demand.

5.2 Adoption impediments

However, even though the resource potential is high, there exist a number of barriers to renewable uptake in Kaduna State. The greatest obstacle is a high front cost. According to Yadudu (2023), the capital cost of solar PV systems amount to US $1,2001,500/kW compared to US $200300/kW of diesel generators. Although operating costs are lesser, well-established households and SMEs often lack the capital to finance or invest in initial costs. There are also institutional and regulatory issues that limit deployment. According to the article by Zubairu (2024), one of the main issues in the energy profile of Kaduna is the lack of fragmentation in policy rollout and the poor implementation of renewable targets. Competing mandates by state agencies increase the bureaucracy and slowdown in the project approvals, and incentives like tax reduction and feed-in tariff are unclear. According to Hamza and Abdullahi (2023), there was low technical ability among the local government units, which contributed to the low rate of project development and backlog maintenance. Acceptance on social levels is mixed. According to Bala and Yusuf (2020), 45 % of the rural respondents do not believe in the reliability of solar technology, and this is due to failure of systems in the past and no after sales services. urban users also raise the same concern with the performance in rainy seasons. Gendered barriers are also identified by Idris and Hassan (2022): women are less likely to access financing and training and thus are less likely to participate in community energy projects. Lastly, a lack of adequate grid infrastructure and excessive distribution losses (more than 40 %) necessitates the use of diesel generators (Yadudu, 2023). Renewable economies of scale are impaired by weak rural electrification. These barriers need to be addressed through specific finance mechanisms, capacity building, efficient policies, and involvement of stakeholders to establish trust and technical proficiency.

5.3 Climate Mitigation Prospects

The transition of Kaduna State towards renewables in its energy mix has potential climate mitigation. Dabo et al., (2024) estimated solar PV expansion that would reduce annual CO 2 emissions by 200,000 tonnes in the event that 100 MW of new capacity replaces diesel generation. According to the estimates given by Farouk and Sani (2021), by swapping 500 diesel pumps with their solar-powered equivalents, 8,000 tonnes of CO 2 emissions will be evaded within the next ten years. Another saving is the potential of biogas of biomass gasification. According to Abubakar and Musa (2021), the 12 MW of biomass capacity is equivalent to 10 million litres of diesel, and an emission reduction of 27,000 tonnes CO 2 e per year. This is also in line with Nigeria Renewable Energy Master Plan target at 10 % renewable energy level by 2025, which in view places Kaduna as a pioneer state (Memudu, 2024). The renewables also increase resilience. Solar mini-grids in communities covered by Suleiman and Ahmed (2022) offered 95

% uptime in the 2023 dry season in relation to outages that surpassed 30 % on grids. This sort of dependability assists health, education, and small business resilience to climate stress. The social gains and fair proportions of mitigation can be massively bolstered by the incorporation of gender-sensitive training as suggested by Nuhu and Okonkwo (2024). According to Socio-technical transition theory, it is essential to combine technical innovations with the policy and social mobilisation support (Jibril et al., 2024). Kaduna will be able to utilize the increased donor investments US$ 32 million in 2023 to finance pilot mitigation projects and enhance institutional capacity. The renewable deployment in Kaduna may be viewed as a model demonstrated to other states across Nigeria, in case of breaking barriers, where reductions in emissions would apply in very large amounts with the additional effect of promoting sustainable development.

VI. FINDINGS

6.1 Summary of Key Insights

The authors revealed that Kaduna State is well suited to solar power, biomass, and lesser wind farms. The solar radiation of most of the state averages at 4.92 to 7.00 kWh/m 2 /day, which is a good source of base to off-grid and grid-connected solar systems. Decentralised energy solutions can be on the basis of biomass on agricultural waste and organic refuse particularly in rural regions. Nevertheless, wind potential stays at periphery levels as average wind speeds are lower than the commercial viability levels. Kaduna is still dominated by grid electricity and diesel generators. The grid is not very reliable in many communities and in rural areas outages are extensive. Diesel generators serve the purpose but become a source of extra emissions and expenses. There has been a steady increase in the amount of CO 2 emissions as well as the average temperatures experienced over the past ten years. The remaining obstacles facing adoption of renewable energy are initial cost that is very high, lack of awareness, poor implementation of policies and little technical skills. This is due to the institutional inefficiencies and insufficient faith in the government to implement, despite the increasing federal and donor funding. However, the interest of the communities in clean energy is increasing especially in an area where smaller scale solar projects have been implemented relatively well.

6.2 Policy Recommendations

The Kaduna State Government is encouraged to revise its energy and climate policies to consider definite goals regarding renewable integration. The state is to issue renewable energy procurements standards that are to be enforced, and they are to be placed first in the focus of public faculties. There should be a focused Renewable Energy Coordination Unit to ease licensing, land accessibility and tracking of the projects. The development of clean energy systems by both developers and households should be offered tax incentives as well as waivers on import duties. The policy of public procurement should insist on renewable inclusion in new infrastructure. Straightforward frameworks on involving the private sector in mini-grids and community-based plans are also required. Environmental and social monitoring mechanisms need to monitor the impacts.

6.3 Strategy on Investment and Technology

It is necessary to ensure strategic investment to alleviate the heavy up-front cost of renewable systems in Kaduna. The large-scale solar farms are prone to de-risking through public-private partnerships and funding security of smaller organizations. Local banks ought to be propounded to provide soft loans or lease to own to households and small companies that invest in solar. Technical capacity-building, infrastructure increase need to be prioritised by the foreign donor assistance in off-grid areas. Risk-sharing websites and matching grants can boost investor certainty in the clean energy projects as well. Technologically speaking, solar mini-grids should be scaled as reliable electricity supply to rural clusters via standardised kits and modular systems. Smart inverters and net metering should be applied into grid-connected solar installations in case it is possible. Biomass technologies should be tailored to the location of feedstocks, such as compact digesters, and gasifiers. Agricultural cold storage facilities and solar irrigating pumps must be given first priority to minimize diesel consumption in the production of food. Local institutions of tertiary education may find innovation interventions that assist in researching on locally appropriate low-cost technologies. The upgrade of these strategies shall help Kaduna in addressing its climate resilience and increasing the clean energy footprint.

CONCLUSION

The paper evaluated the possibility of renewable energy in decreasing the effects of climate change in Kaduna State in Nigeria. The results affirm that Kaduna has very robust natural resource assets in regards to the development of sustainable energy power; particularly solar radiations and biomass. The most promising source, which is backed up by insolation levels that are steady at up to 7.0 kWh/m 2 /day, is solar PV. Another feasible supplement to decentralised power generation is agricultural wastes and organic refuse which have biomass potential. There is low average wind speeds limiting the wind potential. In spite of these resources, there is low adoption of renewable as renewable energy resources face some barriers such as high cost of installation, scarcity of skilled labour, poor enforcement of regulations and insufficient awareness among the population. The national grid and diesel generators dominate the power sector and continue to lead to the emission of CO 2 and warmer temperatures. The study reveals that renewable energy plants have the potential to generate a steady, low-carbon electricity supply, especially in the rural and peri-urban regions. Kaduna can become a leader of clean energy transition with adequate investment, policies, and technical advice. With a strategic approach, renewable energy provides an avenue towards energy security, economic prosperity and resilience to climate. The collaboration among government, the private sector, and communities is critical to the expansion of renewable energy infrastructure throughout the state because every effort needs to be made to include a coordinated effort.

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