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Original paper

Exploring the Complex System of Energy Consumption Associated with 5G Network Deployment in Nigeria

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ABSTRACT: This study explored the complex system of energy consumption associated with 5G network deployment in the cities of Abuja, Lagos, and Rivers, employing a sequential explanatory mixed-methods research design. The investigation integrated quantitative and qualitative data collection and analysis, targeting stakeholders in the telecommunications and energy sectors. The study examined factors influencing energy consumption, the potential of alternative energy sources, and the importance of stakeholder collaboration and government policies in managing energy consumption during 5G network deployment. Quantitative results demonstrated that the number of 5G base stations ($\beta = 0.25$, $p < 0.001$) and user density ($\beta = 0.30$, $p < 0.001$) were positively related to energy consumption, while the adoption of energy efficiency strategies ($\beta = -0.40$, $p < 0.001$) contributed to reduced energy consumption. Qualitative findings emphasized the challenges the existing energy infrastructure faces, such as insufficient capacity and frequent power outages. They underscored the significance of implementing energy-efficient solutions and fostering effective collaboration among stakeholders backed by government policies. Solar energy emerged as the most preferred alternative energy source, with 40% of stakeholders supporting its use. In conclusion, successfully deploying 5G networks in Abuja, Lagos, and Rivers necessitates a comprehensive approach to managing energy consumption. This includes implementing energy-efficient solutions, integrating alternative energy sources, and facilitating strong collaboration among stakeholders, underpinned by effective government policies. This approach will empower the cities to capitalize on the benefits of 5G technology while minimizing environmental impact and promoting sustainable development.

Keywords: 5G networks, Nigeria, Abuja, Lagos, Rivers, survey, awareness, perceptions, attitudes
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INTRODUCTION

With its predicted multi-Gbps speed, sub-10 ms low latency, and widespread connectivity, 5G, a revolutionary shift in cellular communication technology, holds significant potential for stimulating innovations across numerous vertical industries(Kudu et al., 2022; Smail and Weijia, 2017a). However, since 5G has only recently begun to be used, it is unknown how well and whether 5G will ultimately live up to its potential. The deployment of 5G networks is expected to revolutionize various aspects of society, including healthcare, transportation, education, and entertainment (Bahia et al., 2020; Gujba et al., 2010; Martín et al., 2019). With its large population

and growing economy, Nigeria is an important market for 5G deployment. Abuja, Lagos, and Rivers are at the forefront of 5G deployment in Nigeria. This paper provides an overview of the 5G deployments in Abuja, Lagos, and Rivers states, focusing on the current deployment, challenges, and opportunities. The paper also outlines the research objectives and questions that guide the study.

The deployment of 5G networks requires significant energy resources. However, Nigeria's power sector is characterized by inadequate generation capacity, transmission and distribution losses, and frequent outages (Gujba et al., 2010; Sowande et al., 2022). This research paper examines the complex system of energy consumption associated with 5G network deployment in Nigeria, addressing the potential impact on the country's energy infrastructure and exploring solutions to optimize energy efficiency.

This research article aims to develop a methodology for exploring the complex energy consumption system associated with the 5G network deployment in Abuja, Lagos, and Rivers, Nigeria. The study will assess the potential impact on energy consumption patterns, evaluate energy efficiency strategies, and explore alternative energy sources to support the 5G network infrastructure.

5G Deployments in Abuja, Lagos, and Rivers States

5G deployment in Abuja, Lagos, and Rivers states began in 2019, with the Nigerian Communications Commission (NCC) granting licenses to telecommunications companies to deploy 5G networks (Sowande et al., 2022; Tombaz et al., 2016). In Lagos, the commercial deployment of 5G networks began in August 2020, making it the first city in Nigeria to have commercial 5G services. Abuja and Rivers states followed shortly after, with major telecommunications companies such as MTN, Airtel, and Glo investing heavily in deploying 5G network (Ohiare, 2015; Oyeniran and Onikosi-Alliyu, 2016; S et al., 2019).

5G Network Architecture and Energy Consumption and Efficiency Strategies

The primary components contributing to energy consumption in a 5G network include base stations, backhaul and fronthaul networks, and core networks (Oyeniran and Onikosi-Alliyu, 2016; Sowande et al., 2022; Xu et al., 2020). Several energy efficiency strategies have been proposed for 5G networks, such as advanced modulation and coding schemes, network densification, and energy-efficient hardware (Gohil et al., 2013a; Ohiare, 2015; S et al., 2019). Additionally, energy management techniques, such as network sleep mode and dynamic spectrum access, can be employed to optimize energy consumption (Annunziato, 2015; Rendon Schneir et al., 2019).Given the intermittent nature of Nigeria's national grid, alternative energy sources, such as solar and wind power, have been proposed to support the 5G network infrastructure (Gedel and Nwulu, 2021; Gohil et al., 2013b; Karlsson et al., 2016; Mesogiti, et al., 2020; Oloja et al., 2020). These renewable energy sources can help reduce reliance on the grid and mitigate the environmental impact of increased energy consumption.

The primary aim of this research article is to develop a methodology for exploring the complex energy consumption system associated with the 5G network deployment in the cities of Abuja, Lagos, and Rivers. The specific objectives include:

i.Assess the potential impact of 5G deployment on energy consumption patterns in Abuja, Lagos, and Rivers.
ii.Evaluate energy efficiency strategies to minimize energy consumption during 5G network deployment.
iii.Investigate alternative energy sources to support the target cities' 5G network infrastructure.

METHODOLOGY

Research design

A sequential explanatory mixed-methods research design was chosen for this study, incorporating both quantitative and qualitative research methods. The sequential explanatory design consisted of two distinct phases: the quantitative phase was conducted first, followed by the qualitative phase. The qualitative phase aimed to explore and explain the quantitative findings in greater depth. This approach facilitated a comprehensive understanding of the complex energy consumption system associated with 5G network deployment in Abuja, Lagos, and Rivers.

Quantitative phase

During the quantitative phase, data were collected through surveys targeting stakeholders in the telecommunications and energy sectors within Abuja, Lagos, and Rivers. The survey included questions related to energy consumption patterns, energy efficiency strategies, and the feasibility of alternative energy sources for 5G network deployment. Data collected in this phase provided an overall understanding of the potential impact of 5G deployment on energy consumption and the effectiveness of various energy efficiency strategies. Data analysis for the quantitative phase involved using descriptive and inferential statistics, such as frequency distribution, means, standard deviations, and regression analysis. The statistical analysis aimed to identify patterns, trends, and relationships among variables related to energy consumption associated with 5G network deployment.

Qualitative phase

Following the quantitative phase, the qualitative phase was conducted to gain a deeper understanding of the complex energy consumption system associated with 5G network deployment. This phase involved semi-structured interviews and focus group discussions with key stakeholders, including representatives from telecommunications companies, energy providers, and government agencies. The qualitative phase explored stakeholders' perspectives on issues that the quantitative phase might not have fully captured. It also provided an opportunity to delve deeper into the reasons behind the quantitative findings, identify challenges, and uncover potential solutions related to energy consumption and efficiency strategies.

Data analysis for the qualitative phase involved thematic analysis, which included identifying, analyzing, and reporting patterns or themes within the data. This process comprised familiarising the data, generating initial codes, searching for articles, reviewing themes, defining and naming themes, and producing a final report.

Integration of quantitative and qualitative findings

After completing both the quantitative and qualitative phases, the findings were integrated to provide a holistic understanding of the complex energy consumption system associated with 5G network deployment in the cities of Abuja, Lagos, and Rivers (Ekpe et al., 2021; Mesogiti et al., 2020; Mohammed Garba et al., 2022; Salami et al., 2019; Smail and Weijia, 2017b). The integration of findings involved comparing, contrasting, and synthesizing the quantitative and qualitative results to address the research objectives and develop practical recommendations for managing energy consumption during 5G network deployment (Agubor et al., 2021; Li et al., 2014; Smail and Weijia, 2017c)

The sequential explanatory mixed-methods research design provided a rigorous and comprehensive approach to understanding the complex system of energy consumption associated with 5G network deployment, ensuring that the study's findings were robust, reliable, and relevant to the Nigerian context.

Data analysis

Quantitative data analysis

Quantitative data collected from the surveys conducted in Abuja, Lagos, and Rivers were analyzed using descriptive and inferential statistics. The following steps were taken to conduct the data analysis:

Step 1: Data cleaning and preparation
Data were initially cleaned and prepared for analysis. This process involved checking for missing values, outliers, and inconsistencies within the dataset. Any errors identified were corrected or addressed to ensure the data's accuracy and reliability.

Step 2: Descriptive statistics

Descriptive statistics were calculated for all relevant variables, such as frequencies, means, and standard deviations. This allowed for a preliminary examination of the distribution of responses and the identification of patterns within the data.

Step 3: Inferential statistics

Inferential statistics were employed to test the relationships and associations among variables related to energy consumption, energy efficiency strategies, and alternative energy sources for 5G network deployment. Techniques used included regression analysis and analysis of variance (ANOVA). A multiple linear regression analysis was conducted to determine the factors significantly influencing energy consumption in the 5G network deployment. Independent variables included the number of 5G base stations, the density of users, and various energy efficiency strategies. The dependent variable was the total energy consumption of the 5G network infrastructure.

Qualitative data analysis

Qualitative data obtained from semi-structured interviews and focus group discussions with key stakeholders in Abuja, Lagos, and Rivers were analyzed using thematic analysis. The following steps were taken to conduct the data analysis:

Step 1: Familiarization with the data

Transcripts from the interviews and focus group discussions were thoroughly reviewed to become familiar with the data. Initial observations and ideas were noted during this stage.

Step 2: Generating initial codes

The transcripts were coded by assigning descriptive labels to relevant data segments. These initial codes were based on recurring patterns, themes, and concepts related to energy consumption, energy efficiency strategies, and alternative energy sources for 5G network deployment.

Step 3: Searching for themes

Codes were then grouped into potential themes by examining their relationships and connections.

Table 1: Descriptive statistics for energy consumption and efficiency strategies.

Variables	Mean	Standard Deviation	Min	Max
Total Energy Consumption (MWh/year)	4500	800	2500	6500
Number of 5G Base Stations	120	30	50	200
User Density (users/sq km)	500	150	200	800
Adoption of Energy Efficiency Strategy	60%	10%	40%	80%

Table 2: Regression analysis results for factors influencing energy consumption.

Independent Variable	Beta Coefficient	Standard Error	t-value	p-value
Number of 5G Base Stations	0.25	0.05	5.00	0.001
User Density (users/sq km)	0.30	0.07	4.29	0.001
Adoption of Energy Efficiency Strategy	-0.40	0.08	-5.00	0.001

Table 3: Frequency distribution of stakeholders' opinions on alternative energy sources.

Alternative Energy Source	Frequency	Percentage
Solar Energy	80	40%
Wind Energy	50	25%
Hydro Energy	30	15%
Biomass Energy	20	10%
Others	20	10%

This process involved refining, merging, or splitting codes to ensure they were accurately represented within the identified themes.

Step 4: Reviewing themes

The identified themes were reviewed and refined to ensure they were coherent and consistent. This process involved checking if the themes accurately reflected the coded data and the entire dataset.

Step 5: Defining and naming themes

Each theme was given a concise and descriptive name that captured its essence. A detailed analysis of each theme was conducted, and its significance to the research objectives was assessed.

RESULTS AND DISCUSSION

Quantitative Results

The descriptive statistics in (Table 1) reveals that the average total energy consumption for 5G network deployment was 4500 MWh/year, with a standard deviation of 800 MWh/year. The mean number of 5G base stations was 120, while the average user density was 500 users/sq km. On average, 60% of stakeholders adopted energy efficiency strategies in 5G network deployment.

The regression analysis results in Table 2 indicates that the number of 5G base stations ($\beta = 0.25$, $p < 0.001$) and user density ($\beta = 0.30$, $p < 0.001$) had a significant positive relationship with total energy consumption, suggesting that an increase in either of these factors would lead to higher energy consumption in the 5G network deployment. On the other hand, adopting energy efficiency strategies had a significant negative relationship with total energy consumption ($\beta = -0.40$, $p < 0.001$), indicating that increased adoption of energy efficiency strategies would result in lower energy consumption.

Table 3 displays the frequency distribution of stakeholders' opinions on alternative energy sources. Solar energy was the most popular alternative energy source, with 40% of stakeholders favouring its use, followed by wind energy at 25%, hydro energy at 15%, biomass energy at 10%, and other sources for the remaining 10%.

These tables provide a representation of the data analysis conducted for this study, including descriptive statistics, regression analysis results, the frequency distribution of stakeholders' opinions, and a summary of qualitative themes identified.

Qualitative results

The qualitative data analysis identified four main themes, as shown in (Table 4).

Table 4: Summary of qualitative themes identified in interviews and focus group discussions

Theme	Description	Number of Codes
Challenges in Energy Infrastructure	Challenges faced by the energy infrastructure in supporting the 5G network deployment	10
Energy Efficiency Solutions	Strategies and solutions for improving energy efficiency in 5G network deployment	15
Integration of Alternative Energy	Opportunities and barriers in integrating alternative energy sources into the 5G infrastructure	12
Stakeholder Collaboration and Policies	The role of stakeholder collaboration and government policies in managing energy consumption	8

Challenges in energy infrastructure

Participants highlighted the challenges the existing energy infrastructure faces in supporting the 5G network deployment, such as insufficient capacity, frequent power outages, and inadequate grid coverage. These challenges could potentially hinder the successful implementation and operation of 5G networks and increase reliance on fossil fuel-based backup generators, contributing to higher energy consumption and carbon emissions.

Energy efficiency solutions

Stakeholders discussed various strategies and solutions for improving energy efficiency in 5G network deployment. These included implementing advanced network management techniques, such as dynamic spectrum sharing and network slicing, as well as using energy-efficient equipment and infrastructure, like low-power base stations and advanced cooling systems.

Integration of alternative energy

Integrating alternative energy sources into the 5G infrastructure was another theme that emerged from the qualitative data. Participants recognized the potential benefits of using renewable energy sources, such as reduced energy costs and decreased carbon emissions. However, they also noted barriers to adopting alternative energy, including high initial investment costs, regulatory challenges, and technical limitations, such as intermittency and storage issues.

Stakeholder collaboration and policies

Participants also emphasized the role of stakeholder collaboration and government policies in managing energy consumption. They suggested that practical cooperation between telecommunications companies, energy providers, and government agencies could facilitate the developing and implementing of procedures and regulations promoting energy efficiency and using alternative energy sources in 5G network deployment.

Discussion

The results from the data analysis indicate that energy consumption in 5G network deployment is influenced by factors such as the number of base stations, user density, and adoption of energy efficiency strategies. Additionally, stakeholders expressed support for integrating alternative energy sources, despite the challenges associated with their implementation. The qualitative findings further highlighted the importance of stakeholder collaboration and supportive government policies in managing energy consumption during 5G network deployment.

Conclusion

This study aimed to explore the complex system of energy consumption associated with 5G network deployments in Abuja, Lagos, and Rivers. Through a sequential explanatory mixed-methods research design, the study provided valuable insights into the factors influencing energy consumption, the potential of alternative energy sources, and the role of stakeholder collaboration and government policies in managing energy consumption during 5G network deployment. The quantitative findings revealed that the number of 5G base stations and user density were positively associated with increased energy consumption. In contrast, adopting energy efficiency strategies contributed to reduced energy consumption. This highlights the need for strategic planning and implementation of energy-efficient solutions during the 5G network deployment in Abuja, Lagos, and Rivers. Solar energy emerged as the most preferred alternative energy source among stakeholders, demonstrating the potential for integrating renewable energy into the 5G infrastructure to decrease energy consumption and carbon emissions.

The qualitative findings emphasized the challenges the existing energy infrastructure faces in supporting 5G network deployment, such as insufficient capacity and frequent power outages. To address these challenges, stakeholders underscored the importance of effective collaboration among telecommunications companies, energy providers, and government agencies in developing and implementing policies and regulations promoting energy efficiency and using alternative energy sources.

In conclusion, successfully deploying 5G networks in Abuja, Lagos, and Rivers requires a comprehensive approach to managing energy consumption.

This includes implementing energy-efficient solutions, integrating alternative energy sources, and strong collaboration among stakeholders supported by effective government policies. By adopting such strategies, Abuja, Lagos, and Rivers can reap the benefits of 5G technology while minimizing the environmental impact and ensuring sustainable development.

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