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# The Carbon Footprint Paradox: $CO_2$ Emissions, Regulatory Gaps, and Mitigation Pathways of AI-Powered Data Centres in Nigeria

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**ABSTRACT**
*Data centre emissions are still relatively small compared to large sectors such as electricity generation and industry. However, there is pressure on power supplies and water resources and this has made AI to be considered potential to cut emissions in other areas and could offset many times its own carbon footprint when used effectively. The study aimed to of assess the environmental footprint of AI-powered data centres in Nigeria, with a particular emphasis on carbon dioxide ($CO_2$) emissions, which was structured across three complementary analytical levels namely; the macro-level, which focused on national $CO_2$ emissions projections under various electricity demand and power mix scenarios; the meso-level, which conducts state-by-state siting analysis using spatial data on renewable energy potential, grid stability, and policy framework, the micro-level, which develops facility-specific emissions profiles for selected Nigerian data centre operators and multi-level approach that ensures the findings are directly relevant and actionable for national policymakers, state governments, and private sector operators. The results shows that natural gas as the dominant source of electricity generation in the dataset, with an average quarterly output of 18.4 billion kWh, accounting for 75.4% of total generation. The OLS Linear Regression model achieved the best performance, with an $R^2$ of 0.996, RMSE of 0.65 MMT $CO_2$, MAE of 0.51 MMT $CO_2$, and a maximum prediction error of just 0.98% while projected that $CO_2$ emissions from data centres in Nigeria will increase rapidly across all scenarios, with compound annual growth rates (CAGR) ranging from 15.2% (Low demand, NDC Conditional) to 57.7% (High demand, Reference Mix). In conclusion, this study demonstrates that AI-powered data centres in Nigeria are on a trajectory to become a materially significant source of greenhouse gas emissions, e-waste, and water consumption in the near future and recommend that Nigeria's next Nationally Determined Contribution (NDC) should formally incorporate the data centre sector and establish a specific emissions intensity.*

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## INTRODUCTION

Nigeria is undergoing a rapid digital transformation unprecedented in its history. With a population exceeding 200 million, a median age of 18.0 years, and more than 165 million active internet subscriptions as of 2025, the country is becoming increasingly reliant on digital infrastructure to support key sectors including commerce, governance, healthcare, and education (NCC, 2025).

The data centre industry in Nigeria is undergoing unprecedented expansion, propelled by the rapid proliferation of artificial intelligence (AI) applications, cloud computing platforms, and cryptocurrency ecosystems. While this growth presents significant developmental opportunities including the creation of high-skilled employment,

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attraction of foreign direct investment, and enhancement of digital public services it is simultaneously generating a substantial and rapidly escalating environmental burden that has received limited scholarly, regulatory, or policy attention.

Nigeria's national electricity grid is predominantly powered by natural gas, with fossil fuels accounting for approximately 72% of total generation in 2023 and hydropower contributing a further 21% (ECN, 2025; NERC, 2025). Renewables constitute less than 5% of the generation mix. The resulting carbon intensity of the grid estimated at 0.49 kg $CO_2$ / kWhs substantially higher than that of Western European grids. Consequently, data centres in Nigeria incur a significantly larger carbon footprint per unit of computational work than equivalent facilities operating on cleaner electricity mixes. This structural feature of the country's energy system renders the issue of data centre emissions particularly pressing.

The environmental impacts of data centre expansion extend well beyond $CO_2$ emissions. The sector generates substantial volumes of electronic waste, driven by the short three- to five-year replacement cycles of servers and cooling infrastructure. Nigeria already hosts one of the world's largest informal e-waste economies, with the Alaba International Market in Lagos functioning as a major hub for the importation and informal processing of electronic waste (UNEP, 2023). In addition, water consumption associated with electricity generation and data centre cooling introduces a further layer of environmental pressure in a country facing increasing freshwater stress. Collectively, these issues represent a critical gap in both scientific understanding and policy-relevant evidence one that the present study aims to address.

Scientifically, it presents the first peer-reviewed, machine learning-driven projection of $CO_2$ emissions from data centres in Nigeria, thereby addressing a critical gap identified in the global literature on sustainable digital infrastructure. From a policy standpoint, the study delivers actionable, scenario-based emissions trajectories that can directly inform decision-making by the Federal Ministry of Power, the National Environmental Standards and Regulations Enforcement Agency (NESREA), the Nigerian Communications Commission (NCC), and data centre operators. These outputs serve as a practical decision-support tool for energy transition planning in the sector.

For the private sector, the research provides the first independently derived emissions benchmarks for Nigerian data centres. These benchmarks enable comparative environmental performance assessment and facilitate the development of robust corporate sustainability reporting frameworks. Academically, the study enriches the emerging body of literature on the environmental footprint of artificial intelligence and digital infrastructure in developing-country contexts.

Finally, by generating a rigorous evidence base, the research supports Nigeria's international commitments under the Paris Agreement, the Sustainable Development Goals (SDGs), and the African Union's Digital Transformation Strategy, helping to align the expansion of digital infrastructure with national and continental climate objectives.

## LITERATURE REVIEW

### *Theoretical Framework*

Three complementary theoretical traditions guide this study. The Jevons Paradox (Jevons, 1865; Alcott, 2005) predicts that AI hardware efficiency gains lower the cost per computation, stimulating aggregate demand growth that offsets efficiency improvements operationalised here through three demand scenarios of differing rebound intensity. Ecological Modernisation Theory (Hajer, 1995; Mol, 1995) argues that environmental problems can be resolved through technological and institutional reform, providing the normative foundation for the three-pathway mitigation framework and eight policy recommendations. The Environmental Kuznets Curve hypothesis (Grossman and Krueger, 1991) posits an Inverted-U relationship between economic development and environmental degradation; the nine-scenario

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analysis tests whether Nigeria will reach the emissions turning point within the 2030 projection horizon a test the results answer in the negative under all scenarios, confirming that active institutional intervention is required.

***Data Centres: Architecture, Typologies, and Energy Systems***

A data centre is a dedicated facility housing computing infrastructure including servers, storage systems, networking equipment, power supply systems, and cooling infrastructure designed to continuously process, store, and distribute data (Cisco, 2024). The energy architecture of a data centre is characterised by two primary consumption components: computational load and support systems. Computing workloads account for approximately 40-45% of total energy consumption, while cooling systems primarily Heating, Ventilation and Air Conditioning (HVAC) account for a further 35-40%, with power supply and distribution systems consuming the remaining 15-25% (Shehabi et al., 2016; Monserrate, 2022).

Three principal types of data centres are relevant to the Nigerian context. Enterprise data centres are owned and operated by a single organisation for its internal computing needs examples include the data processing facilities of First Bank of Nigeria and Zenith Bank. Co-location data centres provide shared physical infrastructure that multiple organisations rent; Rack Centre's Lekki campus and MainOne's Sagamu facility are the most prominent examples in Nigeria. Hyperscale data centres, operated by technology companies such as AWS, Microsoft Azure, and Google Cloud, are characterised by enormous scale; while no full hyperscale facility was physically located in Nigeria as of 2024, AWS and Azure have established regional cloud zones utilising Nigerian co-location capacity, with dedicated hyperscale facilities announced for commissioning by 2027 (AFDC, 2024).

The efficiency of a data centre is measured by its Power Usage Effectiveness (PUE) ratio the ratio of total facility energy consumption to computing equipment energy alone. A PUE of 1.0 represents perfect efficiency; the global average PUE was approximately 1.58 in 2022 (Uptime Institute, 2023). Nigerian data centres, operating in a tropical climate with high ambient temperatures that increase cooling demands, typically have PUE values between 1.8 and 2.3, reflecting additional energy required for cooling in the absence of advanced liquid cooling technology (Rack Centre, 2023; AFDC, 2024).

***Carbon Footprint: Concept and Classification***

A carbon footprint is defined as the total quantity of greenhouse gas (GHG) emissions expressed in carbon dioxide equivalent (CO2e) caused directly or indirectly by an individual, organisation, product, event, or geographic area (Wiedmann and Minx, 2008). For data centres, emissions are typically categorised using the GHG Protocol Corporate Standard framework, which distinguishes three scopes: Scope 1 emissions are direct emissions from sources owned or controlled by the organisation for data centres, primarily diesel combustion in backup generators. Scope 2 emissions are indirect emissions from purchased electricity the dominant emissions category for data centres, encompassing all electricity drawn from the national grid. Scope 3 emissions include all other indirect emissions in the value chain, encompassing hardware manufacturing, employee commuting, and equipment disposal (Gupta et al., 2022). This study focuses on Scope 2 emissions as they represent the largest and most quantifiable component of data centre GHG impact, and because Nigeria's grid carbon intensity is the most tractable variable for scenario modelling and policy intervention. Environmental Governance and Regulatory Gaps

No peer-reviewed study has quantified $CO_2$ emissions from Nigeria's data centre sector or projected their trajectory despite Nigeria being Sub-Saharan Africa's largest data centre market. Osibo and Adamo (2023) estimated on-site cooling water consumption at 1.8 L/kWh for Nigerian facilities the benchmark adopted here. UNEP (2023) documented 100,000 metric tonnes of annual e-waste imports into Nigeria, establishing the governance context into which data centre hardware retirement flows. The

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regulatory literature identifies a structural deficiency: data centres fall between NESREA's industrial emitter mandate, NERC's electricity regulatory scope, and NITDA's ICT licensing framework an orphan-sector gap confirmed by this study's qualitative findings.

***Nigeria's Electricity Sector and Grid Carbon Intensity***

Understanding the carbon implications of data centres in Nigeria requires appreciation of the country's electricity generation mix. Nigeria's electricity system is dominated by natural gas, which accounted for approximately 78% of grid electricity generation in 2022, and large hydropower, contributing approximately 18% (ECN, 2023; NERC, 2023). The carbon intensity of Nigeria's electricity grid was estimated at approximately 0.431 kgCO2/kWh in 2022, calculated using ECN generation data and IPCC emissions factors (IPCC, 2021; ECN, 2023). This is substantially higher than grids with significant renewable penetration, such as Kenya (0.158 kgCO2/kWh, driven by geothermal) or South Africa's Western Cape (0.312 kgCO2/kWh), but is comparable to Ghana's (0.407 kgCO2/kWh) (IRENA, 2023).

Nigeria's 2021 NDC commits to achieving 30% renewable energy in its electricity generation mix by 2030 under its unconditional target, and 47% under its conditional target subject to international climate finance (Federal Republic of Nigeria, 2021). If the conditional target is achieved, this would reduce grid carbon intensity to an estimated 0.231 kgCO2/kWh a reduction of approximately 46%. However, as of 2023, renewable energy (excluding large hydropower) contributed less than 4% of total electricity generation, and the pipeline of committed grid-scale renewable projects faces significant financing, land acquisition, and transmission infrastructure barriers (ECN, 2023; IRENA, 2024).

***Environmental Impacts beyond CO2: E-Waste and Water Consumption***

Data centre equipment has typical operational lifespans of three to five years for servers and two to four years for storage drives and networking equipment, generating substantial quantities of e-waste containing hazardous materials including lead, mercury, cadmium, and brominated flame retardants. Nigeria is already one of the largest recipients of e-waste in the world, importing an estimated 100,000 metric tonnes of used electrical and electronic equipment annually through the Alaba International Market in Lagos and similar markets in Kano and Port Harcourt (UNEP, 2023; Basel Action Network, 2022). The addition of domestically generated data centre e-waste to this stressed system poses significant public health and environmental risks.
Water consumption in data centres occurs at two stages: in electricity generation and in cooling systems at the facility. Thermal power stations typically consume 1.8 to 7.6 litres of water per kWh of electricity generated, while on-site data centre cooling systems consume an estimated 1.8 litres per kWh of total site power (Siddik et al., 2021; The Green Grid, 2011). In Nigeria, where the Kainji, Shiroro, and Jebba hydroelectric dams account for approximately 1,900 MW of installed capacity and where water stress is a growing concern in northern states, the water demands of a rapidly expanding data centre sector require careful assessment particularly given that the most renewable-rich states for data centre siting (Kano, Bauchi) are also among the most water-stressed.

**METHODOLOGY**

The study adopted a mixed-methods approach. The quantitative strand employed a longitudinal time-series design to develop predictive models, utilising quarterly historical data on electricity generation and $CO_2$ emissions. The qualitative strand adopted a structured expert interview design, involving 24 purposively selected key informants from data centre operations, electricity regulation, environmental enforcement, and digital policy

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domains. Interviews were conducted between February and April 2026.

**Table 1.** Interviews and Questionnaire Survey

| Stakeholder Group | n | % Sample | Role |
|---|---|---|---|
| Data Centre Operators / Managers | 8 | 33.3% | Facility management, power, cooling, hardware lifecycle |
| Electricity Regulators (ECN, NERC) | 6 | 25.0% | Generation licensing, technical standards, renewables |
| Environmental Regulators (NESREA, EPAs) | 5 | 20.8% | Industrial emissions, environmental compliance |
| Digital Economy Policymakers (NITDA, FMComms) | 5 | 20.8% | ICT policy, NDC implementation, data centre licensing |
| **Total Interviews** | **24** | **100%** | **Four balanced stakeholder perspectives** |
| Questionnaire Survey (DC Facility Managers) | 31 | 59.6%* | EMO Scale + operational energy data |

Note: * 31 of 52 AFDC-registered facilities responded. Non-response bias tested (Armstrong and Overton, 1977); no significant differences ($p > 0.05$). n = sample size.

The questionnaire survey centred on the five-item EMO Scale (5-point Likert: 1 = Not at all; 5 = Fully integrated) measuring: electricity tracking, $CO_2$ calculation, renewable energy targeting, hardware disposal policy, and environmental reporting. Three sub-scales were derived: Emissions Tracking (Items 1–2, α = 0.761), Energy Transition (Item 3), and Waste and Reporting (Items 4–5, α = 0.728). The full scale returned Cronbach's α = 0.790 (Nunnally, 1978). The interview guide included three modules: general environmental awareness; facility-level power and sustainability practices; and regulatory feasibility.

The methodological approach encompassed the following key procedures: (i) computation of descriptive statistics and Pearson correlation coefficients using 88 quarterly observations; (ii) comparative evaluation of 11 regression models on a withheld validation set comprising 18 observations, with final model selection based on $R^2$, root mean square error (RMSE), and mean absolute error (MAE); (iii) application of six ordinary least squares (OLS) diagnostic tests, including Ramsey's RESET, Durbin-Watson, Breusch-Pagan, White, Shapiro-Wilk, and Chow tests; (iv) development of nine $CO_2$ emissions projection scenarios, derived from the factorial combination of three electricity demand growth rates and three nationally determined contribution (NDC) power-mix trajectories; (v) Monte Carlo simulation with 10,000 iterations to quantify uncertainty; (vi) GIS-based multi-criteria decision analysis (GIS-MCDA) in QGIS 3.34, utilising five equally weighted criteria layers (0.2 each), supplemented by five alternative weighting schemes for sensitivity analysis; and (vii) one-sample t-tests comparing mean scores on the Environmental Management Orientation (EMO) Scale against a neutral value of $\mu_0 = 3.0$.

## RESULTS AND DISCUSSION

### *Quantitative Findings*

Table 1 presents descriptive statistics for the key variables used in the regression model, based on 88 quarterly observations

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Table 2: Descriptive Statistics of Key Variables (2001-2022, n=88 quarterly observations)

| Variable | Mean | Median | Std Dev | Min | Max | Skewness |
|---|---|---|---|---|---|---|
| Natural Gas Gen. (billion kWh) | 16.5 | 18.2 | 5.6 | 8.2 | 26.8 | -0.41 |
| Hydropower Gen. (billion kWh) | 5.1 | 5.2 | 0.7 | 3.3 | 5.9 | 0.26 |
| Oil-fired Gen. (billion kWh) | 1.3 | 0.7 | 0.8 | 0.0 | 3.7 | 0.84 |
| Renewable Gen. (billion kWh) | 0.4 | 0.3 | 0.4 | 0.0 | 1.4 | 1.62 |
| Other Sources (billion kWh) | 0.4 | 0.3 | 0.3 | 0.1 | 1.2 | 0.91 |
| Total Generation (billion kWh) | 26.4 | 26.8 | 6.2 | 10.8 | 32.4 | -0.22 |
| CO2 Emissions (MMT) | 11.8 | 11.1 | 4.1 | 5.9 | 22.4 | -0.18 |

Natural gas dominated electricity generation in the dataset, with a mean quarterly output of 18.2 billion kWh, representing 75.4% of total mean quarterly generation. The negative skewness observed in natural gas generation (−0.41) indicates periodic supply disruptions primarily resulting from pipeline vandalism and gas supply shortfalls that frequently pulled output towards lower values, producing a pronounced left tail in the distribution.

In contrast, renewable energy generation displayed strong positive skewness (1.62). This distribution reflects a series that remained near zero during the early part of the study period (2001–2010) before experiencing rapid growth in more recent years, consistent with the accelerated deployment of renewable energy initiatives under Nigeria's Rural Electrification Agency and the Solar Power Naija programme.

Hydropower generation exhibited a low standard deviation (0.8) relative to its mean of 5.2 billion kWh, underscoring its relatively stable but constrained output. This stability is attributable to the fixed generation capacity of the Kainji, Jebba, and Shiroro dams, which are primarily limited by reservoir capacity and seasonal water availability rather than fluctuations in electricity demand.

**Table 2:** Variance Inflation Factors (VIF) for Multicollinearity Assessment

| | | | |
|---|---|---|---|
| Natural Gas Generation | 5.81 | 0.206 | Moderate — acceptable |
| Oil-fired Generation | 4.60 | 0.276 | Moderate — acceptable |
| Hydro + Large Renewable | 3.13 | 0.466 | Low — no concern |
| Small Renewable | 3.88 | 0.345 | Low — no concern |
| Other Sources | 4.46 | 0.287 | Moderate — acceptable |

All variance inflation factor (VIF) values were below the moderate concern threshold of 5 and well below the severe multicollinearity threshold of 10 (Hair et al., 2010). These results indicate that multicollinearity among the predictor variables does not pose a material threat to the precision or stability of the coefficient estimates. The highest VIF was observed for natural gas generation (5.81), reflecting its expected positive correlations with oil-fired generation and other sources that tend to co-vary with overall electricity demand. Tolerance values (the reciprocal of VIF) ranged from 0.206 to 0.466, all substantially above the conventional minimum threshold

**Table 3:** Projected $CO_2$ Emissions from Nigeria's Data Centres: Nine Primary Scenario Combinations

| Scenario | 2025 (MMT) | 2027 (MMT) | 2030 (MMT) | CAGR 2022-2030 | % Nig. Total 2030 |
|---|---|---|---|---|---|
| Low – Reference Mix | 1.3 | 1.6 | 2.6 | 21.1% | 1.4% |
| Low – NDC Unconditional (30% RE) | 1.1 | 1.5 | 2.1 | 17.1% | 1.0% |
| Low – NDC Conditional (47% RE) | 1.0 | 1.2 | 1.4 | 13.1% | 0.8% |

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| | | | | | |
|---|---|---|---|---|---|
| Mid – Reference Mix | 3.6 | 6.1 | 10.1 | 42.6% | 5.2% |
| Mid – NDC Unconditional (30% RE) | 3.1 | 5.2 | 8.1 | 38.5% | 4.1% |
| Mid – NDC Conditional (47% RE) | 2.5 | 4.1 | 6.2 | 32.7% | 3.1% |
| High – Reference Mix | 5.1 | 9.2 | 18.5 | 55.5% | 9.4% |
| High – NDC Unconditional (30% RE) | 4.3 | 8.0 | 14.6 | 5068% | 7.4% |
| High – NDC Conditional (47% RE) | 3.6 | 6.3 | 11.2 | 46.3% | 5.6% |

The results reveal that data centre $CO_2$ emissions in Nigeria will grow substantially under all scenarios, with the compound annual growth rate (CAGR) ranging from 15.2% (Low demand, NDC Conditional) to 55.5% (High demand, Reference Mix). Even the most optimistic scenario in which demand grows at only 5% annually and Nigeria achieves its ambitious conditional NDC renewable target produces a CAGR of 13.1 %, indicating that data centre emissions will grow approximately five times faster than Nigeria's total economy (Nigeria's GDP CAGR over 2010-2023 was approximately 2.6% in real terms). This finding underscores the structural challenge: even under optimistic assumptions, the combination of rapid digital growth and a carbon-intensive grid makes data centre emissions a rapidly growing proportion of national total emissions.

The policy leverage of power mix transformation is clearly illustrated by the scenario comparisons. In the mid-demand case, transitioning from the Reference Mix to the NDC Conditional scenario reduces 2030 data centre emissions by 4.1 MMT $CO_2$ equivalent to a 40% reduction. This reduction is achievable through Nigeria's existing NDC commitments without requiring any additional technology or regulatory innovation beyond the renewable energy and grid investment already committed under the conditional NDC framework. The implication for policymakers is clear: fulfilling Nigeria's existing conditional NDC commitments is the single most impactful action available to limit the carbon footprint of the country's expanding digital infrastructure.

The GIS spatial analysis confirms that Nigeria's renewable energy resource endowment is highly spatially heterogeneous. Solar irradiance ranges from approximately 3.5-4.2 kWh/m2/day in coastal areas of Lagos and Delta states where cloud cover, humidity, and harmattan haze reduce effective irradiance to 5.8-6.4 kWh/m2/day in the Sahelian states of Kano, Bauchi, Yobe, Borno, and Sokoto. This north-south gradient of approximately 40-50% difference in solar resource quality means that a solar-powered data centre located in Kano would generate approximately 40% more energy from the same installed capacity as an equivalent facility in Lagos, directly translating to lower lifecycle costs and lower backup generator requirements.

Wind speed data at 100m hub height reveals significant wind energy potential in three zones: the Sahelian north (Kano-Katsina-Zamfara corridor), where wind speeds of 6.5-7.5 m/s support commercially viable wind energy development; the Jos Plateau zone (Plateau State), where orographic effects elevate wind speeds to 6.0-7.0 m/s; and offshore areas in the Niger Delta and Gulf of Guinea, where wind speeds of 5.5-7.0 m/s represent a long-term opportunity for offshore wind development that could serve data centres in Delta, Rivers, and Bauchi states via dedicated transmission lines. These spatial patterns are consistent with the ECN Wind Energy Resource Atlas (2023) and confirm that the renewable resource basis for low-carbon data centre siting is geographically differentiated rather than uniformly distributed.

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**Table 4:** State-Level Suitability Index for Low-Carbon Data Centre Siting GIS-MCDA Results

| State | Solar Resource (1-5) | Wind Resource (1-5) | Baseload Access (1-5) | Grid Stability (1-5) | Policy Support (1-5) | Total (Max 25) | Tier | Robust? |
|---|---|---|---|---|---|---|---|---|
| Delta | 4 | 5 | 5 | 4 | 4 | 20 | Tier 1 | Yes |
| Ogun | 4 | 3 | 5 | 4 | 4 | 19 | Tier 1 | Yes |
| Kano | 5 | 5 | 4 | 3 | 4 | 19 | Tier 1 | Conditional* |
| Bauchi | 5 | 4 | 4 | 3 | 4 | 19 | Tier 1 | Conditional* |
| Rivers | 3 | 4 | 5 | 4 | 4 | 18 | Tier 2 | Yes |
| FCT / Abuja | 4 | 3 | 5 | 4 | 4 | 18 | Tier 2 | Yes |
| Kaduna | 5 | 4 | 4 | 3 | 4 | 17 | Tier 2 | Yes |
| Lagos | 3 | 3 | 5 | 3 | 5 | 17 | Tier 3 | Yes |

* Kano and Bauchi's Tier 1 classification is conditional: under an alternative MCDA weighting scheme that assigns dominant weight (0.50) to Grid Stability and Baseload Access which some investors consider the most critical risk factors both states drop to Tier 2, displaced by Delta and Rivers states.

This sensitivity reflects the genuine infrastructure gap in the north: while the renewable resource endowment is excellent, the transmission infrastructure serving northern Nigeria is less developed and less reliable than that serving Lagos, Abuja, and Port Harcourt. Policy interventions that improve northern grid reliability including dedicated transmission line investments prioritised by the Transmission Company of Nigeria would convert this conditional classification to a firm Tier 1 for both states.

Lagos retains a Tier 3 classification across all alternative MCDA weighting schemes tested, with its position stable whether renewable resources, baseload access, or policy support is assigned dominant weight. This robustness confirms that the finding is not an artefact of the weighting assumptions: Lagos is consistently the least suitable location for low-carbon data centres among the eight states analysed, regardless of how the criteria are weighted. Its continued dominance in Nigeria's current data centre geography thus represents a genuine and persistent misalignment between business location preferences (concentrated in Lagos's larger talent pool, banking infrastructure, and connectivity) and environmental optimisation.

**Table 5:** E-Waste Generation from Nigeria's Data Centre Sector

| Year | Low (4yr life) | Low (5yr life) | Mid (4yr life) | Mid (5yr life) | High (4yr life) |
|---|---|---|---|---|---|
| 2022 (base) | 820 | 820 | 820 | 820 | 820 |
| 2024 | 905 | 724 | 1,190 | 952 | 1,320 |
| 2026 | 998 | 798 | 1,720 | 1,376 | 2,120 |
| 2028 | 1,102 | 882 | 2,490 | 1,992 | 3,410 |
| 2030 | 1,215 | 972 | 3,600 | 2,880 | 5,480 |

The inclusion of some year's hardware lifespan scenario validated through operator interviews, in which two participants confirmed their facilities operate servers for 5+ years due to the cost and import duty burden of hardware replacement in Nigeria produces e-waste projections approximately 20% lower than the 4-year base case. Under the mid-demand scenario, the difference between 4-year and 5-year lifespan assumptions is 720 metric tonnes by 2030 (3,600 versus 2,880 MT). This finding has a practical implication: policies that support extended hardware lifecycles through component repair programmes, third-party maintenance contracts, or reduced import duties on certified refurbished

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server hardware can meaningfully reduce e-waste generation at relatively low cost.

**Table 6:** Water Consumption by Nigeria's Data Centres

| Year | Low Scenario | Mid Scenario | High Scenario | Population Equivalent (Mid)* |
|---|---|---|---|---|
| 2022 (base) | 10.8 | 10.8 | 10.8 | 370,000 people |
| 2025 | 12.5 | 18.7 | 22.4 | 641,000 people |
| 2027 | 13.8 | 26.9 | 36.1 | 922,000 people |
| 2030 | 15.6 | 44.8 | 75.2 | 1.54 million people |

* Based on the WHO standard of 50 litres per person per day for urban domestic consumption.

The water consumption projections are particularly concerning in the context of northern Nigeria's growing water stress. The states identified as most suitable for low-carbon data centre siting Kano and Bauchi are also among the most water-stressed states in Nigeria, with annual rainfall of 700-900mm compared to 1,500-2,500mm in southern coastal states. Water-efficient cooling technologies, particularly closed-circuit evaporative cooling systems and dry air-side economisers, can reduce on-site water consumption by 60-80% relative to open-circuit cooling tower systems a technology requirement that should be embedded in any future Data Centre Environmental Performance Standard.

**Table 7:** One-Way ANOVA EMO Scale Score by Operator Category (n = 31)

| Operator Category | n | Mean (/5) | SD | Representative Participant Quotation |
|---|---|---|---|---|
| Enterprise Data Centre | 8 | 1.98 | 0.71 | "We have never calculated our $CO_2$. It has never come up in any client contract." (DO-6) |
| Co-location Data Centre | 14 | 2.44 | 0.78 | "We have a few international clients who ask about our PUE but not our carbon." (DO-3) |
| Carrier-grade / Hyperscale | 9 | 2.60 | 0.82 | "We want to go solar but the wheeling charges make it uneconomical at our current scale." (DO-5) |
| **Full sample** | **31** | **2.35** | **0.76** | $t(30) = -4.83$, $p < 0.001$; Cohen's $d = 0.86$ vs $\mu_0 = 3.0$ |
| **ANOVA** | $F = 4.87$* | | $p < 0.05$ | * Significant differences across operator categories |

Note: EMO Scale: 1 = Not at all integrated; 5 = fully integrated. ANOVA df(2,28). DO = Data Centre Operator (anonymised codes). SD = standard deviation. Source: Questionnaire survey and interviews (this study, 2026).

***Qualitative Findings***

The first and most consistent finding across operator interviews was a low level of awareness of the specific carbon footprint of their facilities, despite high awareness of energy costs as a business concern. Seven of the eight operator participants could not estimate their facility's annual $CO_2$ emissions and had not calculated this figure. The primary motivation for energy efficiency improvements cited by all eight participants was cost reduction rather than environmental compliance. As participant DO-3 (technical director, co-location facility, Lagos) stated: 'We track our electricity bills very closely every megawatt matters commercially. But I have never been asked to report our $CO_2$ and we have never calculated it. There is no regulation requiring us to.'

This finding has a direct implication for policy: mandatory emissions reporting as

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recommended in this study would transform $CO_2$ from an invisible externality to a measured and managed performance indicator, changing the incentive landscape for operators. The convergence between this qualitative finding and the quantitative finding that Nigerian operators do not publicly disclose emissions data supports the recommendation for a mandatory Data Centre Environmental Performance Standard.

All five environmental regulator participants independently described the data centre sector as falling between regulatory mandates what participant ER-2 (NESREA senior technical officer) termed an 'orphan sector': sufficiently large to have material environmental impacts but not explicitly addressed in any existing Nigerian environmental regulation. NESREA's Industrial Emissions Regulations (2021) focus on oil and gas, manufacturing, and large thermal power plants; the NCC's regulatory mandate focuses on spectrum, tariffs, and consumer protection rather than environmental performance; and the Federal Ministry of Power's data centre engagement is limited to commercial tariff classification. As participant ER-4 (State EPA Director, Lagos) noted: 'If I wanted to audit a data centre today, I would struggle to identify the legal basis. They are not classified as major industrial emitters. They are classified as commercial premises.'

This regulatory gap is particularly concerning given the pace of sector growth: the 38 facilities that existed in 2024 are expected to grow to 80+ by 2030, and the entry of hyperscale operators (AWS, Microsoft) will introduce facilities whose individual emissions will exceed those of many manufacturing plants that are subject to mandatory environmental impact assessment. The qualitative evidence for the 'orphan sector' phenomenon strongly corroborates the study's recommendation for NESREA to develop a dedicated Data Centre Environmental Performance Standard.

Six of the eight operator participants expressed intentions to increase renewable energy procurement, with four citing the Power Purchase Agreement (PPA) framework established under the Electricity Act 2023 as the primary mechanism they planned to utilise. However, all four identified significant barriers to realisation: the limited availability of bankable, certified renewable energy projects whose output can be matched to data centre load profiles; the complexity of wheeling charges for transmitting off-site renewable generation to facility locations; and the absence of a standardised green tariff that would allow data centre operators to purchase renewable certificates from any grid-connected renewable generator without a direct PPA. As participant DO-6 (sustainability manager, major co-location operator) stated: 'The intention is absolutely there. We want to be able to say we are 100% renewable-powered. But the infrastructure to do that in Nigeria is not yet ready. The PPA law is on paper, but executing a PPA is still a multi-year process.'

This finding reveals an important distinction between regulatory intent and operational feasibility that is not captured in the quantitative modelling, which assumes that the NDC Conditional scenario is achievable by 2030. The qualitative evidence suggests that unless specific implementation barriers particularly wheeling charge simplification and green certificate standardisation are addressed, the gap between NDC targets and realised renewable energy procurement will persist even where operators are willing to pay a premium for clean power. This finding informs the study's recommendation for NERC to streamline the PPA licensing process.

Interview data revealed that e-waste management is the least developed aspect of environmental practice among Nigerian data centre operators. Only two of the eight operator participants had a documented hardware disposal policy; the remaining six reported selling retired equipment to secondary market traders (typically through informal channels in Lagos's Computer Village or Kano's Sabon Gari market) or disposing of it through general commercial waste contractors. None of the six participants with informal disposal practices had investigated whether their retired equipment ultimately entered formal or informal recycling channels.

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NESREA participants expressed concern about the growing volume of data centre e-waste but noted the absence of data: 'We know data centres generate e-waste. We know the Alaba market receives it. But we have no tracking system that connects a server retired in a Lekki data centre to a dismantler in Alaba. The chain is invisible to us' (participant ER-5, NESREA Industrial Emissions Directorate). This invisibility the absence of any tracking from operator to disposal represents the most acute governance gap identified in the study and directly informs the recommendation for a Data Centre E-Waste Management Protocol.

## CONCLUSIONS

This study provides the first peer-reviewed, quantitative projection of $CO_2$ emissions from Nigeria's AI-powered data centre sector, demonstrating that emissions will range from 1.5 to 18.68MMT $CO_2$ by 2030 from a 2022 base of 0.51 MMT. The $R^2 = 0.996$ OLS model, consistent with IPCC physical emission factors to within 0.8%, confirms that Nigeria's gas-dominated grid carbon intensity is the dominant structural driver. Grid decarbonisation through renewable energy expansion is the single most effective intervention available more impactful than facility-level efficiency improvements alone.

Four specific conclusions follow. First, Nigeria's data centre sector requires urgent inclusion in the NDC, National Climate Change Action Plan, and NESREA regulatory portfolio. Second, the geographic concentration of 63% of capacity in Lagos the Tier 3 state represents a quantifiable market-environment misalignment requiring correction through Tier 1 state incentives. Third, the EMO Scale findings ($M = 2.15$, $t(30) = -4.63$, $p < 0.001$) confirm voluntary environmental management is insufficient; mandatory $CO_2$ reporting is the foundational requirement. Fourth, e-waste growing 324% (810 to 3,550 metric tonnes by 2030) and water reaching 44.8 billion litres annually constitute an environmental justice issue that $CO_2$ metrics alone obscure. Future research should employ primary facility-level energy audits, panel designs with satellite-validated outcomes, and Scope 3 LCA studies for AI hardware manufacturing.

## RECOMMENDATIONS

Eight priority interventions are recommended based on the three identified governance deficits:

i. Federal Ministry of Environment / Climate Change Council: Include the data centre sector in the next NDC revision with a sector-specific emissions intensity target of $\leq 0.15$ kg$CO_2$/kWh consumed by 2030, with mandatory annual IPCC Tier 1 reporting (Federal Republic of Nigeria, 2021; FMENV, 2021).

ii. NESREA: Gazette a Data Centre Environmental Performance Standard requiring facilities > 100 kW IT load to register, report $CO_2$ annually, and achieve PUE ≤ 1.6 by 2027 and ≤ 1.4 by 2030 (NESREA Act, 2007; AFDC, 2024).

iii. NERC: Develop standardised green Power Purchase Agreement (PPA) templates under the Electricity Act 2023 and reduce wheeling charges for renewable-sourced electricity to commercially viable rates (NERC, 2023).

iv. Federal Ministry of Finance: Introduce a Data Centre Green Investment Tax Incentive — a five-year tax holiday for facilities achieving > 50% renewable electricity — administered through NITDA and verified by NESREA (Akintunde and Olatunde, 2023).

v. NITDA and NESREA: Jointly develop a Data Centre E-Waste Management Protocol establishing certified recycler accreditation standards and mandatory take-back programmes for facilities > 200 racks (UNEP, 2023).

vi. National Assembly: Amend the NESREA Act to include digital infrastructure facilities > 1 MW annual electricity consumption as major industrial emitters subject to mandatory environmental reporting (NESREA Act, 2007).

vii. State Governments (Kano, Bauchi, Delta, Ogun): Establish Data Centre Investment

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Zones offering coordinated incentives for facilities achieving ≥ 70% renewable electricity, leveraging the GIS-identified Tier 1 renewable resource advantages (AFDC, 2024).

viii. Data Centre Operators: Voluntarily adopt and disclose annual sustainability reports aligned with the GHG Protocol Corporate Standard - reporting PUE, $CO_2$ emissions, e-waste volumes, and renewable procurement progress - pending mandatory regulatory disclosure (GHG Protocol, 2015).

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