

Carbon Emissions in Nigerian University Libraries: A Comparative Analysis across the Six Geopolitical Zones

Kayode Sunday John Dada^{1,*}, Romoke Opeyemi Quadir²

¹University Library, Federal University of Education, Zaria, Kaduna State, Nigeria

²Nigerian Defence Academy Library, Kaduna / Department of Library and Information Science, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

*Corresponding Author: Kayode Sunday John Dada, kayodescholar@gmail.com

Article History

Received: 18 June 2026

Revised: 24 September 2026

Accepted: 28 September 2026

Available Online: 21 October 2026

Abstract. Background: University libraries are among the most energy-intensive spaces within Nigerian academic campuses, operating extended daily hours and housing power-demanding equipment including server rooms, lighting arrays, reprographic facilities, and climate-control systems. Despite their substantial contribution to institutional operations, the environmental footprint of these buildings — expressed through institutional greenhouse gas (GHG) emissions — remains poorly quantified across Nigeria's six geopolitical zones. This study investigates carbon emissions in federal and state university libraries across Nigeria by examining energy-use patterns, emission sources, and the structural barriers hindering decarbonisation in these regions. **Methods:** Employing a concurrent (convergent) mixed-methods design, this study surveyed 24 university libraries — 12 federal and 12 state institutions, four purposively selected from each of Nigeria's six geopolitical zones — between January and June 2025. Quantitative energy-inventory and Likert-scale barrier data and qualitative open-ended responses were collected concurrently and integrated at the interpretation stage. Data were collected through a self-developed energy-inventory questionnaire and structured facility checklists administered to a designated primary respondent (the University Librarian or deputy) at each library, supplemented by input from unit heads and maintenance officers where relevant. Emission sources were classified according to the GHG Protocol Corporate Standard across Scopes 1, 2, and 3, applying an operational-control approach to define the library's organisational boundary. **Results:** Diesel-powered generators constituted the largest source of Scope 1 emissions in the sampled libraries, accounting for an

estimated 42-68% of direct emissions, reflecting the combined effect of constant generator use and unreliable grid electricity supply. Fluorescent and incandescent lighting remained predominant in 79% of surveyed libraries, and air-conditioning units in 65% of facilities were older, higher-energy-intensity models. Descriptively large inter-zonal differences were observed — South-West zone libraries showed comparatively higher adoption of energy-saving technologies and on-site solar generation, whereas North-East zone libraries reported the most constrained infrastructure — although, given the small per-zone sample ($n = 4$), these differences should be interpreted as indicative rather than confirmatory. Institutional and financial budgetary constraints were the most highly rated perceived barrier to decarbonisation, followed by the absence of institutional energy policy and inadequate staff awareness. **Conclusions:** The findings point to the value of a coordinated national framework for integrating energy-efficiency standards into university library management, active stakeholder participation, and phased adoption of renewable energy technologies to reduce the carbon footprint of academic libraries in Nigeria, in line with the country's Nationally Determined Contributions and Sustainable Development Goal 13. Because the sample was purposively — not randomly — selected, these findings should be read as an in-depth, geographically diverse case comparison rather than as statistically generalisable to all Nigerian university libraries.

Key words. Carbon emissions, Decarbonisation, Energy efficiency, Nigerian universities, University libraries

1. Introduction: Carbon Emissions from University Libraries in Nigeria

Tertiary higher education institutions (HEIs) in Nigeria form one of the largest concentrations of institutional energy consumers on the African continent; as of 2024 the country had 274 licensed universities, against which the National Universities Commission (NUC) reported that only around 700,000 of roughly two million annual applicants could be admitted, indicating a system of comparable scale to the earlier estimate of over 200 universities cited in this field [1]. University libraries occupy a distinctive position within this system because of their extended hours of operation — commonly 10-16 hours per day, seven days a week — and the range of energy-intensive equipment they house, including computer workstations, centralised server rooms, reprographic machinery, archival preservation units, and extensive lighting arrays [2,3]. In a national electricity environment characterised by persistent unreliable grid supply, libraries are compelled to rely on diesel-powered generators for a significant proportion of their operating hours, elevating their Scope 1 carbon emissions [4]. The contribution of HEIs to global greenhouse gas (GHG) emissions has attracted scholarly attention across several regions [5,6], and institutions across Europe, North America, and Asia have progressively developed methods for quantifying campus-level carbon footprints and proposing decarbonisation strategies [2,7]. The African higher education landscape, and Nigeria in particular, remains comparatively under-represented in this evidence base [7]. Adeyeye et al. conducted an institution-level carbon inventory at a Nigerian university and found that direct emissions from fossil-fuel combustion — driven by constant generator use in response to unreliable electricity supply — produced per-capita emission profiles markedly different from those reported for institutions in Organisation for Economic Co-operation and Development (OECD) countries [8], a pattern corroborated at the library-building scale for at least one Nigerian federal university, where diesel and petrol generators were found to account for the majority of an institution's local electricity-related carbon footprint [9].

A university library merits specific investigation for several reasons. First, unlike lecture halls or offices, libraries maintain near-continuous operation across both semesters of the academic year. Second, library buildings are frequently among the oldest structures on any given campus, so that energy-efficiency considerations are often absent from the original building codes and subsequent development plans [10,11] — a pattern this study's own facility survey addresses directly with Nigeria-specific evidence (Section 3.1). Third, libraries provide services — preservation of physical and electronic collections, stable internet connectivity, and lit reading spaces — that create institutional disincentives to reduce energy consumption without deliberate strategic planning. Nigeria's six geopolitical zones (North-Central, North-East, North-West, South-East, South-South, and South-West) exhibit pronounced differences in climate, infrastructure quality, institutional funding, and access to

the national electricity grid [4], which plausibly give rise to inter-zonal variation in library carbon emission intensities, though this variation has rarely been documented systematically. This gap motivated the present study, which investigates emission sources, consumption patterns, and decarbonisation barriers across federal and state university libraries in all six zones. By treating the library as the unit of analysis, the study complements broader campus-level carbon footprint assessments and offers insights of direct relevance to library management, university estates departments, and national education policymakers. The findings are further situated within Nigeria's Nationally Determined Contributions (NDCs) under the Paris Agreement, which commit the country to an unconditional 20% reduction in GHG emissions by 2030.

1.1 Background: Carbon Emissions from University Libraries

Globally, HEIs are significant contributors to GHG emissions through their teaching, research, residential, and administrative operations [2,12]. The carbon footprint (CF) of a university encompasses Scope 1 emissions from direct combustion, Scope 2 emissions from purchased energy, and Scope 3 emissions from supply chains, commuting, and business travel, as defined by the GHG Protocol Corporate Standard and elaborated in ISO 14064-1 [13,14]. Within campuses, library buildings have repeatedly been identified as high-intensity energy consumers in institutional CF studies [2,3]. In Sub-Saharan Africa the picture is complicated by structural energy deficits: Whereas Scope 2 emissions from purchased electricity dominate the footprint of comparable institutions in Europe and North America, Nigerian tertiary institutions facing prolonged grid outages instead show elevated Scope 1 emissions driven by diesel combustion [4,8]. Adeyeye et al. reported that unstable electricity supply at a Nigerian university drove constant generator use that dominated the institution's GHG inventory, a pattern broadly consistent with wider analyses of institutional energy use in low- and middle-income countries [8].

Lighting constitutes a further major emission source in library facilities. Despite the global transition toward energy-saving light-emitting diode (LED) technology promoted by standards bodies and sustainability organisations, many university libraries in resource-constrained settings continue to rely on fluorescent and incandescent fixtures, which consume substantially more energy per lumen than LED alternatives [8]. Similarly, the frequent use of individual split-unit air-conditioning systems rather than centralised, variable-refrigerant-flow systems contributes to elevated electricity demand and, under generator-powered operation, to direct fossil-fuel combustion. As libraries expand institutional repositories and electronic-resource provision, the associated server rooms add a further, continuous source of energy demand and heat load requiring additional cooling capacity [2,3]. Paper consumption, although declining with the shift toward digital platforms, remains a non-

trivial Scope 3 source, particularly for printing and reprographic services [2].

Systematic CF data for Nigerian university libraries nonetheless remains limited in the published literature. Helmers et al., in a global review of university carbon footprinting, found that African institutions were almost entirely absent from the international evidence base, attributing this gap to limited institutional capacity for systematic GHG accounting and the absence of a universally adopted reporting standard [5]. The present study addresses this gap by applying the GHG Protocol Corporate Standard [13] to a purposively selected sample of Nigerian university libraries distributed across all six geopolitical zones.

1.2 Carbon Emissions Classification and Organisational Boundary

The study classifies emissions according to the three-scope framework established by the GHG Protocol Corporate Standard [13], which is widely adopted as the basis for university carbon accounting in the international literature [12,14]. Scope 1 encompasses direct emissions from sources owned or controlled by the library, principally diesel combustion in backup electricity generators and petrol combustion in library-operated transport. Scope 2 addresses indirect emissions from grid-supplied electricity, reflecting the GHG intensity of Nigeria's predominantly gas-fired national grid. Scope 3 covers other indirect emissions, including staff and student commuting, procurement of paper and library materials, outsourced cleaning and maintenance, and the embodied emissions of IT equipment.

Because scope classification depends on ownership and operational control rather than on which activities merely serve the library, this study defines the library's organisational boundary using the operational-control approach recommended by the GHG Protocol [13,15]: An emission source is attributed to the library's Scope 1 or Scope 2 inventory only where the library administration has the authority to introduce and implement operating policy for that source (for example, library-managed generators, air-conditioning units, and lighting and IT circuits within the library building). University vehicles, centrally metered campus generators, and other shared infrastructure that serve the library but remain under the operational control of the wider university estates department are excluded from the library's Scope 1 and Scope 2 totals; where library-attributable usage of such shared assets could be reasonably apportioned from institutional records, it is instead reported as a Scope 3 (upstream service) estimate, and where it could not be apportioned it is excluded and flagged as a boundary limitation (see Section 5). This clarification is necessary because several emission categories reported in Section 3.2 notably petrol-fuelled university vehicles and centrally shared air-conditioning and refrigerant circuits straddle this boundary and are reported here as library-attributable estimates rather than as fully independent library-owned assets.

It is also necessary to correct a conceptual distinction that is easily blurred in discussions of Nigerian institutional energy: Diesel-powered backup generators are a form of fossil-fuel combustion and are neither renewable nor equivalent to a grid-connected renewable-energy system. In contexts where grid-supplied electricity is unstable or largely unavailable, Nigerian university libraries have historically invested heavily in diesel generator capacity as their principal alternative power source, rather than in on-site renewable generation such as solar photovoltaic (PV) systems with battery storage, which would instead reduce generator runtime and displace fossil-fuel combustion [16,17]. Scope 1 dominance in the Nigerian context, relative to the Scope 2 primacy typical of OECD university libraries, therefore reflects this structural reliance on fossil-fuel backup generation rather than any renewable-energy pathway, and the discussion throughout this paper distinguishes consistently between grid electricity (Scope 2), backup fossil-fuel generation (Scope 1), and on-site renewable generation (a mitigation option, not a baseline emission source).

1.3 From Literature to Research Objectives

The literature reveals two related gaps. First, there is a scarcity of empirical, library-specific carbon-emission data for Nigerian universities: Existing CF studies have generally examined campus-level aggregates [7,8] without disaggregating the library component. Second, most Nigerian institutional energy studies to date have adopted a single-site or single-zone approach rather than a systematic geopolitical-zone comparison of how structural, climatic, and institutional differences across Nigeria's regions shape library energy consumption and GHG emissions. Coverage of all six zones in the present sample does not, by itself, establish that the resulting 24-library sample is statistically representative of the national population of Nigerian university libraries; the sample is more accurately described as a purposively selected, geographically diverse comparison group, and this study's claims are scoped accordingly throughout (see Section 2.3 and Section 5).

Building on these gaps, the study developed three interconnected objectives: (i) to quantify and compare GHG emission sources across university libraries in Nigeria's six geopolitical zones; (ii) to identify institutional, financial, and technical barriers to decarbonisation specific to the Nigerian university library context; and (iii) to propose evidence-based strategies and a stakeholder engagement framework for reducing the carbon footprint of university libraries in Nigeria. These objectives translate into the following research questions:

RQ1. How do estimated GHG emission sources and their relative contributions across Scopes 1-3 vary across federal and state university libraries in Nigeria's six geopolitical zones?

RQ2. What institutional, financial, and technical barriers do library administrators perceive as impeding

decarbonisation, and how does the ranking of these barriers appear to vary by zone and institution type?

RQ3. What evidence-based strategies, informed by the identified barriers and by documented cases of good practice within the sample, could support a stakeholder engagement framework for reducing the carbon footprint of Nigerian university libraries?

These questions are addressed descriptively and comparatively rather than through confirmatory hypothesis testing, consistent with the exploratory scope appropriate to a nascent evidence base [18].

2. Methods

2.1 Study Design and Unit of Analysis

This study employed a concurrent (convergent) mixed-methods design [18], in which quantitative data (the energy-inventory questionnaire and the Likert-scaled barriers instrument) and qualitative data (open-ended responses on barriers and good-practice narratives) were collected in parallel from the same 24 libraries and integrated at the interpretation stage, with quantitative data given priority in addressing RQ1 and qualitative data given priority in addressing RQ2. This is consistent with established approaches to CF assessment in HEIs [14,19]. Examination of institutional electricity bills and fuel procurement records is described throughout this paper as document or administrative-record review rather than as a systematic review in the methodological sense, since no formal, pre-registered review protocol was applied to these institutional documents. The unit of analysis for the quantitative energy inventory and the barrier scores is the individual library (n = 24); where more than one staff member contributed information at a given library, responses were reconciled by the designated primary respondent — the University

Librarian or nominated deputy — before submission, so that each library contributes a single set of values to the analysis.

2.2 Sampling Framework and Study Sites

A stratified purposive sampling strategy was adopted to select four university libraries from each of Nigeria's six geopolitical zones: Two from federal universities and two from state universities, enabling comparison by funding type and institutional profile. The resulting sample of 24 library facilities is distributed across 12 federal and 12 state universities, as shown in Table 1.

The federal universities included in the sample receive nationally accredited library services and have historically received capital allocations from the Tertiary Education Trust Fund (TETFund). State universities operate under the funding authority of their respective state governments and exhibit greater variability in infrastructure quality and operational budgets. Selection within each stratum prioritised institutions with accessible energy records and a University Librarian or Deputy University Librarian willing to participate, following ethics approval from the participating universities' institutional review boards (see Ethics Statement). This purposive, access-driven selection procedure introduces a plausible selection bias toward better-resourced and more transparently administered libraries within each zone; a complete sampling frame documenting the total number of eligible libraries per zone and the numbers formally contacted, participating, and declining was not centrally compiled during data collection, and its absence is acknowledged here as a methodological limitation (Section 5). Consequently, the sample should be read as a purposively selected, geographically diverse case comparison rather than as a nationally representative random sample, and no claim of statistical generalisability to the full population of Nigerian university libraries is made.

Table 1. Sampled university libraries by geopolitical zone and funding type.

Geopolitical zone	University library (federal)	University library (state)
North-Central	Abubakar O. Suleiman Library, University of Abuja; Paul Unongo Library, University of Jos	Nasarawa State University Library, Keffi; Benue State University Library, Makurdi
North-East	University of Maiduguri Central Library; Abubakar Tafawa Balewa University Library, Bauchi	Gombe State University Library, Gombe; Adamawa State University Library, Mubi
North-West	Kashim Ibrahim Library, Ahmadu Bello University, Zaria; Sultan Bello Library, Usman Dan Fodio University, Sokoto	Kebbi State University Library, Kebbi; Kano State University of Science and Technology Library, Wudil
South-East	Nnamdi Azikiwe Library, University of Nigeria, Nsukka; Federal University of Technology Owerri Library	Enugu State University of Science and Technology Library; Ebonyi State University Library, Abakaliki
South-South	J.D. Horsfall Library, University of Port Harcourt; University of Calabar Library, Calabar	Rivers State University Library, Port Harcourt; Akwa Ibom State University Library, Ikot Akpaden
South-West	Kenneth Dike Library, University of Ibadan; Hezekiah Oluwasanmi Library, Obafemi Awolowo University, Ile-Ife	Lagos State University Library, Ojo; Olabisi Onabanjo University Library, Ago-Iwoye

Note. Federal = federal government-funded; State = state government-funded. All libraries surveyed between January and June 2025.

2.3 Data Collection Instruments

Three complementary instruments were employed. First, a structured energy-inventory questionnaire (EIQ) was administered to University Librarians, deputies, unit heads, and Estate Department maintenance officers to record installed generator capacity (kVA), average daily generator runtime (hours), monthly diesel consumption (litres), lighting inventory by technology type (incandescent, fluorescent, LED), air-conditioning capacity (BTU), and IT equipment load. No independent physical inspections, meter installations, or calibrated measurements were carried out as part of this study; the inventory instead relies on respondent-reported nameplate capacities and usage patterns, cross-checked against available documentary fuel and electricity records. This survey-and-record-based approach is more accurately described as a desk-based energy inventory than as a physical energy audit, and the terminology used throughout this paper reflects that distinction. Second, a 5-point Likert-scaled barriers questionnaire assessed respondents' perceptions of obstacles to decarbonisation (5 = to a very great extent; 1 = not at all), consistent with the approach applied in comparable international studies [12,20]. Third, copies of electricity bills, fuel procurement records, and any available utility reports were requested for the 12-month period preceding the survey, subject to approval from the relevant university authorities.

The instruments were reviewed by a panel of five experts in library administration and management, energy engineering, and environmental science before administration. A pilot test was conducted at two libraries not included in the main sample — the Akin Deko Library, Federal University of Agriculture, Abeokuta (South-West), and the Ibrahim Badamasi Babangida University Library, Lapai (North-Central) — and revisions were made to improve clarity and reduce completion time. All 24 approached libraries agreed to participate; because institutions were approached on the basis of the purposive criteria described in Section 2.2 rather than drawn from a documented eligible population, this 100% completion rate reflects response among the

pre-selected sample rather than a response rate against a full sampling frame.

2.4 Emission Calculation Method

CF calculations followed the GHG Protocol Corporate Standard [13] and drew on ISO 14064-1 guidance for organisational-level inventories [14,21], applying the organisational boundary defined in Section 1.2. For Scope 1 emissions, diesel consumption was converted to CO₂ equivalents using the IPCC default emission factor of 2.68 kgCO₂ per litre of diesel [22]. For Scope 2 emissions, grid electricity consumption was converted using a Nigeria-specific national grid emission factor of 0.431 kgCO₂/kWh. This data follows values reported in the Nigerian renewable-energy literature [4] and was cross-checked qualitatively against the generation-mix composition reported by the Nigerian Electricity Regulatory Commission (NERC) for the study period; because published country-level grid factors for Nigeria vary somewhat by source, methodology, and year, this value should be treated as an informed approximation rather than a single authoritative annual statistic, and studies requiring higher precision should adopt NERC's most recently published annual generation-mix factor directly. Scope 3 emissions from staff commuting were estimated using a simplified vehicle-kilometre approach based on self-reported commuting distance, typical travel frequency, and predominant transport mode per respondent, without disaggregation by vehicle occupancy or vehicle category; this simplification is noted as a source of uncertainty in Section 5. Paper consumption was converted using a factor of 4.22 kgCO₂e per ream of A4 paper [2]. Results are reported both as total annual tonnes of CO₂ equivalent (tCO₂e) and on a per-staff-and-student-equivalent (per capita) basis, where the staff-and-student-equivalent denominator for each library is defined as the sum of full-time library staff and the number of students formally registered as active borrowers at that library for the 2024 academic year.

Table 2 summarises the emission factors, units, sources, and applicable scopes used throughout this study (see also Figure 1), addressing the need for a single transparent reference table across all emission categories.

Table 2. Emission factors, units, and sources applied in this study.

Emission source	Factor	Unit	Scope	Source / year
Diesel combustion	2.68	kgCO ₂ /L	1	IPCC default factor, 2006 Guidelines
Petrol combustion	2.31	kgCO ₂ /L	1	IPCC default factor, 2006 Guidelines
Grid electricity	0.431	kgCO ₂ /kWh	2	Nigeria national grid factor; Aliyu et al. (2015), cross-checked against NERC generation-mix data, 2024-25
Paper (A4, per ream)	4.22	kgCO ₂ e/ream	3	Valls-Val & Bovea (2021) literature-derived factor
Staff/student commuting	Vehicle-km × mode-specific factor	kgCO ₂ e/km	3	Simplified vehicle-kilometre approach, self-reported

Note. All factors are applied uniformly across libraries in the absence of site-specific metering; this is acknowledged as a source of estimation uncertainty (Section 5). CO₂ is used as the reported unit for direct fuel combustion following common practice in comparable Scope 1 fuel-based calculations; CH₄ and N₂O contributions from stationary combustion are not separately quantified in this study and are treated as a minor addition subsumed within the CO₂e totals reported for grid electricity and paper, consistent with IPCC Tier 1 simplification.

Diesel combustion	2.68 kgCO ₂ / L	1 Scope	IPCC default factor, 2006 Guidelines
Petrol combustion	2.31 kgCO ₂ / L	1 Scope	IPCC default factor, 2006 Guidelines
Grid electricity	0.431 kgCO ₂ / kWh	2 Scope	Nigeria national grid factor; Aliyu et al. (2015), cross-checked against NERC data, 2024-25
Paper (A4, per ream)	4.22 kgCO ₂ e / ream	3 Scope	Valls-Val & Bovea (2021) literature-derived factor
Staff / student commuting	variable kgCO ₂ e / km	3 Scope	Simplified vehicle-kilometre approach (distance × mode-specific factor), self-reported

Note. All factors are applied uniformly across libraries in the absence of site-specific metering; this is acknowledged as a source of estimation uncertainty. CH₄ and N₂O contributions from stationary combustion are not separately quantified and are subsumed within reported CO₂e totals, consistent with IPCC Tier 1 simplification.

Figure 1. Emission factors, units, and sources applied in this study. Note. A reference-card summary of every emission factor used in the study, its unit, applicable GHG Protocol scope, and source. Because the underlying units differ (per litre, per kWh, per ream, per km), factors are presented as individually labelled reference cards rather than as a directly comparable bar chart. Figure created by the authors from the study's own data (Table 2); © 2026 the authors. No third-party copyrighted material is reproduced in this figure.

To demonstrate the reproducibility of the calculation approach, consider an illustrative (non-observed) library reporting average diesel consumption of 500 litres per week: Weekly Scope 1 diesel emissions = 500 L × 2.68 kgCO₂/L = 1,340 kgCO₂ (1.34 tCO₂e); annualised over 52 weeks this yields approximately 69.7 tCO₂e per year from diesel combustion alone. The same procedure was applied library-by-library using each institution's own reported consumption values to generate the ranges reported in Table 3.

A source-by-scope accounting matrix was maintained internally during data processing to avoid double counting between categories — for example, ensuring that electricity attributed to air-conditioning and IT equipment under their own line items in Table 3 was not also included within the general “grid electricity (lighting, equipment)” category, and that operational IT electricity was kept distinct from the embodied emissions of IT procurement and from fugitive refrigerant leakage. The reporting period requires a brief clarification: Fieldwork (surveys and record requests) was conducted between January and June 2025, but respondents were asked to report activity data for the preceding 12 months, which for most libraries corresponded predominantly to the 2024 calendar year; where a library's most recent complete 12-month record spanned parts of both 2024 and early 2025, that record was used as reported and annualised, and the estimates in this paper are described as referring to “recent 12-month” rather than strictly calendar-year 2024 activity. Seasonal variation (e.g., reduced generator use during academic recesses) is not separately modelled and is noted as a limitation.

2.5 Data Analysis

Descriptive statistics were computed for all quantitative variables. Inter-zonal comparisons were assessed using non-parametric Kruskal-Wallis tests given the small sample size within each zone ($n = 4$ per zone, $n = 24$ overall). With only four libraries per zone, this test has limited statistical power and results should be interpreted as indicative of descriptively large differences rather than as robust confirmatory evidence; formal post-hoc pairwise comparisons with correction for multiple testing were not conducted in this analysis owing to the small per-zone cell sizes, and this is treated as a limitation to be addressed through library-level data reporting in future work (Section 5) rather than through additional pairwise significance claims that the current sample cannot reliably support. Likert-scale barrier data were aggregated to mean scores and ranked. Qualitative responses to open-ended questions were subjected to thematic analysis following the six-phase framework of Braun and Clarke [23], conducted by two coders working independently before comparing and reconciling codes through discussion; a formal inter-coder reliability statistic was not computed, which is acknowledged as a methodological limitation. All statistical analyses were conducted in IBM SPSS Statistics version 28.0.

3. Results and Discussion

3.1 Profile of Sampled Libraries

All 24 approached university librarians or deputies agreed to participate, yielding complete data collection

across the pre-selected sample (Section 2.3). The participating libraries ranged in size from 1,850 to 42,300 gross square metres (GSM) of floor space, reflecting considerable variation in institutional scale. Federal university libraries were, on average, 3.1 times larger in floor area than state university libraries. The majority of surveyed libraries (87.5%) were constructed before 1990 — a Nigeria- and library-specific finding from the present survey that supports the broader concern, raised elsewhere in the international literature [10,11], that older library buildings were not designed with contemporary energy-efficiency or archival-climate requirements in mind — and none had undergone comprehensive energy retrofitting, which respondents attributed to the absence of a sustainability policy and to inadequate funding. Renewable-energy installations were present in only two libraries (8.3%), both in the South-West zone: A 10 kWp rooftop solar array at the Kenneth Dike Library, University of Ibadan, commissioned in 2023, and a 5 kWp solar system at the Hezekiah Oluwasanmi Library, Obafemi Awolowo University.

All 24 libraries reported reliance on diesel generators as a primary or secondary electricity source during periods of grid unavailability. Where available, grid power was described as intermittent, with reported average daily

availability ranging from 0 hours — reported by two of the two state-university libraries sampled in the North-East zone — to a maximum of 11 hours at one South-West library. The mean daily grid availability across all 24 libraries was 3.4 hours, consistent with the structural dependence on generator power documented in broader analyses of Nigerian institutional energy [4,17].

3.2 Carbon Emission Sources and Zonal Comparisons

Table 3 and Figure 2 present the range of estimated annual CO₂ emissions across the 24 sampled libraries, calculated using the factors in Table 2 and the boundary defined in Section 1.2. The dominant emission source in every zone was diesel combustion by generators, ranging from a minimum of 58.4 tCO₂e per year at the smallest state university library to a maximum of 812.7 tCO₂e per year at the largest federal university library, consistent with diesel generation contributing an estimated 42-68% of total library emissions depending on zone. Lighting, air conditioning, IT equipment, and paper consumption were secondary contributors across all zones, consistent with findings from library CF studies in comparable institutional contexts [2,3].

Table 3. estimated annual carbon emissions by operational category across 24 sampled Nigerian University libraries.

Emission category	Scope	Min (tCO ₂ e/yr)	Max (tCO ₂ e/yr)	Mean (tCO ₂ e/yr)
Diesel generator combustion	1	58.4	812.7	284.3
Petrol-fuelled university vehicles (library-attributable share)	1 / 3 ¹	1.2	18.6	6.4
Air conditioning and refrigerants	1 & 2	4.3	96.1	31.8
Grid electricity (lighting, equipment)	2	0.4	38.7	11.2
IT equipment (servers, computers)	2 & 3	2.1	44.5	14.3
Paper consumption and printing	3	0.6	9.8	3.7
Staff commuting	3	3.1	27.6	11.9
Procurement (cleaning, maintenance)	3	0.3	6.2	2.1

Note. Scope 1 = direct emissions; Scope 2 = indirect from purchased energy; Scope 3 = other indirect. Data are estimated values for the most recent complete 12-month period of activity reported by each library (predominantly calendar year 2024; see Section 2.4). Min and Max represent the lowest and highest values across the 24 libraries. ¹University vehicles are reported under Scope 1 only where they fall within the library's defined operational-control boundary (Section 1.2); where control could not be confirmed, the library-attributable share is reported as an apportioned Scope 3 estimate.

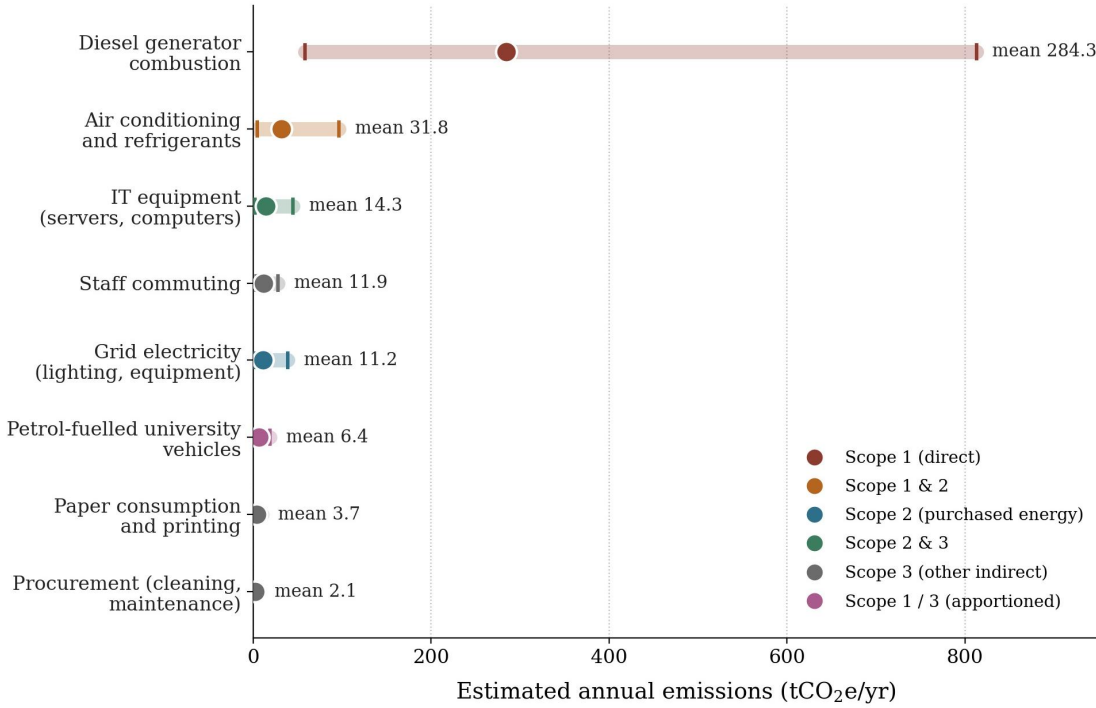


Figure 2. Estimated annual carbon emissions by operational category across 24 sampled Nigerian University libraries. Note. Dots mark the mean; horizontal bars span the reported minimum-maximum range across the 24 sampled libraries. Colour indicates the applicable GHG Protocol scope. Diesel generator combustion is the dominant category by a wide margin, consistent with the 42-68% Scope 1 contribution reported in the text. Figure created by the authors from the study's own data (Table 3); © 2026 the authors. No third-party copyrighted material is reproduced in this figure.

Table 4 and Figure 3 report mean per capita emission intensities by zone and institution type. A Kruskal-Wallis test indicated a descriptively large difference across zones ($H(5) = 14.23$, $p = 0.014$); given the small per-zone sample ($n = 4$) noted in Section 2.5, this result is best read as evidence of substantial variability worth further investigation rather than as a definitive, generalisable finding, and no post-hoc pairwise zone comparisons are reported here. The North-East zone recorded the highest mean per capita emissions, at 2.41 tCO₂e per staff-student equivalent per year, associated descriptively with complete grid absence at several surveyed facilities and correspondingly high generator

runtime; a causal interpretation would require controlling for confounders such as floor area, operating hours, and building age, which this cross-sectional design did not measure jointly. The South-West zone recorded the lowest mean, at 0.94 tCO₂e per capita, associated descriptively with comparatively better grid access, greater uptake of LED lighting, and the two installed solar systems. The North-West and North-Central zones occupied intermediate positions, at 1.87 and 1.64 tCO₂e per capita respectively, while the South-East and South-South zones averaged 1.32 and 1.18 tCO₂e per capita respectively.

Table 4. Mean per capita carbon emissions (tCO₂e/yr) by geopolitical zone and institution type.

Geopolitical zone	Federal (mean)	libraries	State (mean)	libraries	Zonal mean	Primary emission driver
North-Central	1.71		1.57		1.64	Generator combustion; ageing HVAC
North-East	2.53		2.29		2.41	Complete grid absence; diesel dependency
North-West	1.94		1.80		1.87	Generator use; inadequate insulation
South-East	1.40		1.24		1.32	Generator use; fluorescent lighting
South-South	1.21		1.15		1.18	Generator use; humidity-driven cooling load
South-West	0.89		0.99		0.94	Partial grid access; early LED adoption
National Mean	1.61		1.51		1.56	—

Note. Per capita is calculated as total annual library emissions divided by the staff-and-student-equivalent denominator defined in Section 2.4, using 2024 academic-year registration figures. The zonal mean is the simple average of the federal and state library means for that zone; national mean rows are the simple average across the six zonal means, not a pooled per-library mean, and may therefore differ marginally from a library-level average.

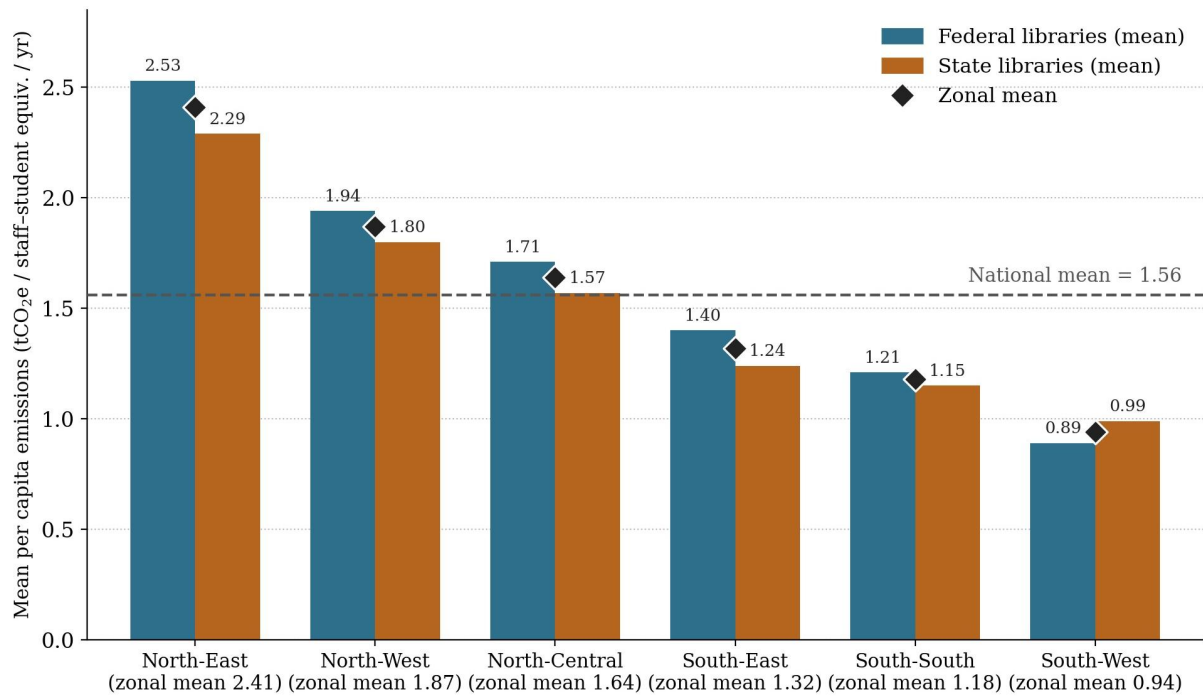


Figure 3. Mean per capita carbon emissions (tCO₂e/yr) by geopolitical zone and institution type. Note. Zones are ordered from highest to lowest zonal mean. The dashed line marks the national mean (1.56 tCO₂e per capita) across all six zones. The black diamond centred on each pair marks the zonal mean (simple average of the federal and state bars). Figure created by the authors from the study's own data (Table 4); © 2026 the authors. No third-party copyrighted material is reproduced in this figure.

These values compare instructively — though not directly, given differences in system boundary, denominator definition, and emission scope between studies — with published benchmarks. Sangwan et al. reported a per capita campus CF of approximately 0.85 tCO₂e per year for an Indian university where grid electricity dominated the footprint, while Adeyeye et al. [24] calculated whole-campus emissions exceeding 2.0 tCO₂e per capita for a Nigerian institution with heavy generator dependence [8]. Because these are whole-campus data with different system boundaries, denominators, and emission scopes than the library-specific per capita data reported here, they should be treated as broadly contextual reference points rather than as a like-for-like comparison; on that basis, the library-specific data are consistent with — but do not on their own establish — the possibility that library buildings are a disproportionately intensive emission node within some Nigerian campuses, particularly in grid-deficient zones. Confirming this would require a within-campus comparison between library and non-library building emissions, which lies beyond the scope of the present study.

Federal university libraries exhibited higher absolute emission totals than their state counterparts across all zones in this sample, plausibly reflecting their generally greater floor area and equipment inventories, though floor-area-normalised intensity values were not separately computed for this comparison and this claim

should therefore be read as a descriptive observation of absolute totals rather than of intensity. State university libraries in the North-East and North-West zones showed comparable or slightly higher per capita emission intensities than their federal counterparts in the same zones (Table 4), which is broadly consistent with more acute grid deficits and, on respondents' accounts, older generator stock in several state institutions; floor-area-normalised intensity data by zone are recommended as a priority for future data collection to test this observation more rigorously.

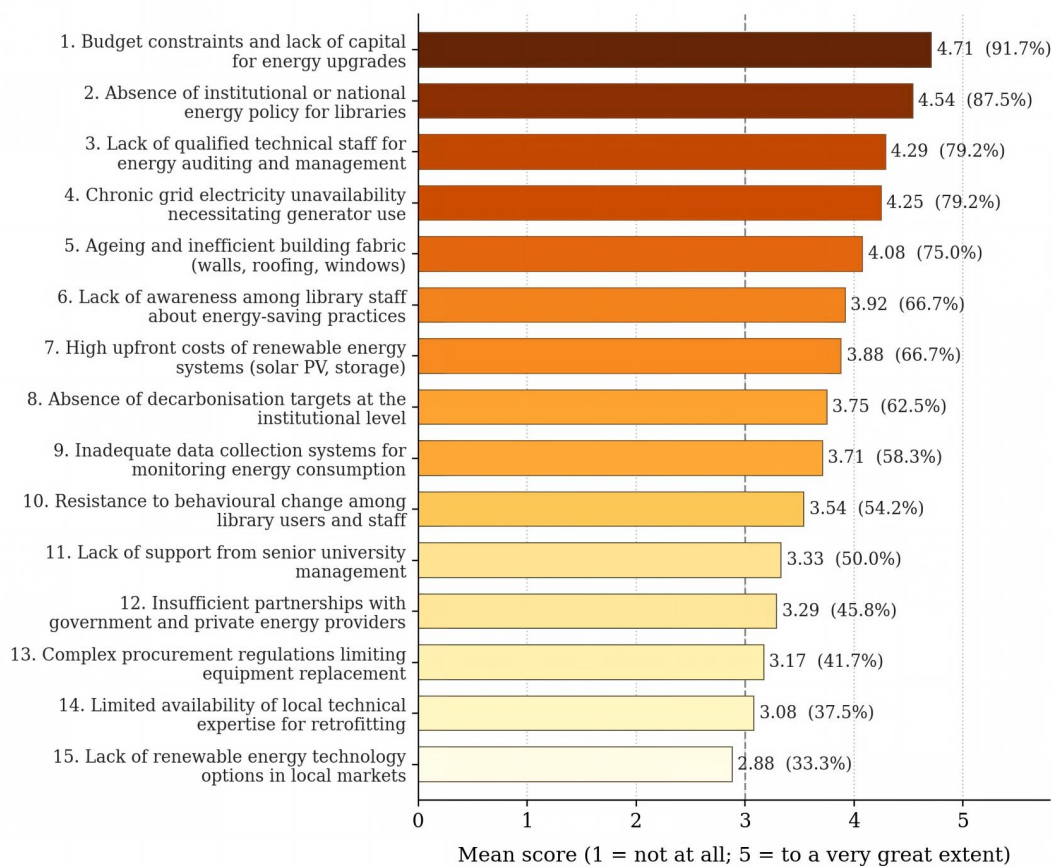
3.3 Barriers to Decarbonisation

Respondents rated 15 potential barriers to decarbonisation on a five-point Likert scale (Table 5 and Figure 4). Because these ratings reflect respondent perceptions rather than independently measured effects, they are described throughout as “perceived barriers” and the highest-rated item is described as the highest-rated perceived barrier rather than as the most critical barrier in an objective sense. Budget constraints and lack of capital for energy upgrades received the highest mean score, cited by 91.7% of respondents as applying to a great or very great extent, mirroring findings from the international literature [12,25]. The absence of a national or institutional policy on library energy management ranked second (87.5%), followed by the lack of qualified technical staff for energy auditing and management (79.2%).

Table 5. Perceived barriers to decarbonisation in Nigerian University libraries (n = 24), ranked by mean score.

Barrier	Mean score (1-5)	Frequency ≥ 4 (%)
Budget constraints and lack of capital for energy upgrades	4.71	91.7
Absence of institutional or national energy policy for libraries	4.54	87.5
Lack of qualified technical staff for energy auditing and management	4.29	79.2
Chronic grid electricity unavailability necessitating generator use	4.25	79.2
Ageing and inefficient building fabric (walls, roofing, windows)	4.08	75.0
Lack of awareness among library staff about energy-saving practices	3.92	66.7
High upfront costs of renewable energy systems (solar PV, storage)	3.88	66.7
Absence of decarbonisation targets at the institutional level	3.75	62.5
Inadequate data collection systems for monitoring energy consumption	3.71	58.3
Resistance to behavioural change among library users and staff	3.54	54.2
Lack of support from senior university management	3.33	50.0
Insufficient partnerships with government and private energy providers	3.29	45.8
Complex procurement regulations limiting equipment replacement	3.17	41.7
Limited availability of local technical expertise for retrofitting	3.08	37.5
Lack of renewable energy technology options in local markets	2.88	33.3

Note. Mean scores based on 5-point Likert scale (1 = not at all; 5 = to a very great extent). Frequency ≥ 4 represents the percentage of respondents rating the barrier as applying to a great or very great extent. These 15 items were the full set of barriers assessed in this study; no items were excluded from reporting.



Note. Bars ranked 1 (highest) to 15 (lowest) by mean Likert score. Value in parentheses is the percentage of respondents rating the barrier 4 or 5 ("great / very great extent"). Darker shading indicates a higher mean score.

Figure 4. Perceived barriers to decarbonisation in Nigerian University libraries (n = 24), ranked by mean score. Note. Bars are ranked 1 (highest-rated) to 15 (lowest-rated) by mean five-point Likert score. The value in parentheses is the percentage of respondents rating the barrier 4 or 5 ("great/very great extent"). Darker shading indicates a higher mean score. Figure created by the authors from the study's own data (Table 5); © 2026 the authors. No third-party copyrighted material is reproduced in this figure.

The dominant role of budget constraints is consistent with findings from Maistry and McKay in South Africa and Whitfield et al. [25] in global health institutions [20]. The second-ranked barrier — absence of energy policy and governance standards — reflects a broader institutional deficit: European HEIs generally operate under national frameworks mandating carbon reporting and energy management, whereas Nigerian universities are not subject to any statutory requirement to measure, report, or reduce GHG emissions. Nigeria's Electricity Act (2023) has begun to decentralise electricity governance and create incentives for renewable integration at state level [17], but this reform has not yet been translated into sector-specific obligations for tertiary education or for libraries specifically.

The combined effect of chronic grid unavailability (ranked fourth) and ageing building fabric (ranked fifth) illustrates what Worsham and Brecha term “carbon lock-in” — a condition in which existing infrastructure and operating procedures perpetuate high-emission outcomes [10]. In the Nigerian university library context, carbon lock-in appears particularly entrenched because generators, once procured, create institutional incentives to maintain diesel infrastructure rather than invest in alternatives, as sunk costs and familiarity with diesel technology make switching both psychologically and financially costly.

The relatively low ranking of “lack of renewable energy technology options in local markets” (ranked fifteenth) suggests that institutional and financial constraints, rather than technical unavailability, are the principal barriers. Solar PV systems are increasingly available in Nigerian urban markets, and their prices have declined over the past decade [4,16]. The primary obstacle to their adoption in university libraries appears to be the absence of capital budget allocations and institutional procurement pathways, consistent with the governance analysis of Mazhar et al. [26].

3.4 Best Practices and Enabling Factors

Among the surveyed libraries, several instances of good practice offer potentially replicable models for others, although the quantitative outcomes reported below were provided by library management as self-reported institutional estimates and were not independently verified through metered before-and-after measurement; they are presented here as institutionally reported evidence rather than as independently confirmed intervention effects. The Kenneth Dike Library at the University of Ibadan has operationalised a 10 kWp solar PV installation which library management reported reduces daytime generator runtime by an estimated 62% during peak sunshine hours, with reported annual savings of approximately 6,200 litres of diesel and 16.6 tCO₂e. The University Librarian attributed this outcome to a dedicated TETFund sustainability grant secured through university management's environmental sustainability drive.

Similarly, Kashim Ibrahim Library, Ahmadu Bello University, Zaria, has implemented an LED lighting retrofit across its ground and first floors, replacing 1,240 fluorescent tubes with LED equivalents at a capital cost that library management reported as recovered within approximately 14 months through reduced fuel consumption. The project was facilitated by an internal energy champion and external support from the MTN Foundation and the MacArthur Foundation, consistent with the recommendation of Maistry and McKay that information centres act as champions in securing institutional buy-in for energy-transition projects [25].

The Nnamdi Azikiwe Library, University of Nigeria, Nsukka, has piloted a user-awareness programme encouraging the shutdown of computer terminals when not in use and the prompt reporting of malfunctioning air-conditioning units. While the associated emission reductions were not separately quantified, the programme illustrates the potential role of library staff and user behaviour in complementing technical interventions, as emphasised by Franco et al. and Kourgiouzou et al. [12,27].

4. Overcoming Structural and Contextual Barriers: Strategies for Nigerian University Libraries

The strategies below are organised to correspond directly to the barriers ranked in Table 5: Policy and governance strategies respond to the first- and second-ranked barriers (budget constraints and absent policy); renewable energy investment responds to the fourth- and seventh-ranked barriers (grid unavailability and high upfront renewable costs); demand-side management and behavioural change respond to the fifth-, sixth-, and ninth-ranked barriers (ageing fabric, staff awareness, and monitoring gaps); and stakeholder participation and long-term planning respond to the third-, eighth-, tenth-, and eleventh-ranked barriers (technical staffing, absent targets, resistance to change, and lack of senior management support).

4.1 Strengthening Institutional Policy and Governance

There is a case for establishing a national energy management framework for Nigerian public university libraries under the auspices of the National Universities Commission (NUC) and the Federal Ministry of Education, in dialogue with the Federal Ministry of Environment. Such a framework could mandate minimum energy performance standards for library buildings, require annual GHG emission reporting using the GHG Protocol or ISO 14064-1 [14,21], and link TETFund capital grants to demonstrable progress against energy reduction targets. Internally, each university could appoint an Energy and Sustainability Officer working within the library building to monitor compliance, an approach that has proven effective in South Africa [25], European higher education [26], and global health institutions [20] that have embedded carbon management within their governance structures. Nigeria's Electricity Act (2023) offers a potential

legislative entry point for such reform at state-university level, though its implementation currently faces capacity and coordination constraints that would need to be addressed alongside any library-specific mandate [17].

4.2 Prioritising Renewable Energy Investment

There is a case for prioritising solar PV systems with battery storage to reduce Scope 1 emissions from generator combustion in Nigerian university libraries [4]. Techno-economic modelling of hybrid photovoltaic-diesel-battery systems for Nigerian tertiary institutions indicates that such systems can meaningfully reduce diesel dependence when sized against real institutional load data [16], and the capital cost of a solar PV system capable of supplying a medium-sized library's daytime load falls within the range of a single TETFund intervention grant at 2025 Nigerian market prices. Phased implementation prioritising high-load zones such as server rooms and reading halls would mirror the staged approach recommended by Palanichamy and Goh for photovoltaic deployment in resource-constrained institutional contexts [28]. The AHP-based prioritisation framework proposed by Campos-Guzmán et al. offers a structured decision tool for libraries seeking to sequence PV investments across multiple buildings [29].

4.3 Demand-Side Management and Behavioural Change

Technical investment could be complemented by structured demand-side management (DSM) programmes, including occupancy-sensor-controlled lighting, programmable thermostats on air-conditioning units, time-of-use electricity tariffs where grid supply is available, and progressive replacement of desktop computers with energy-efficient thin-client terminals in library computer suites. Installing energy-monitoring sub-meters at the distribution-board level in each library unit would provide the granular consumption data necessary for evidence-based decision-making, addressing the monitoring deficit identified by Maistry and Annegarn in comparable institutional settings [30].

Behavioural engagement programmes targeting both library staff and users are equally important. Drawing on the model piloted at the Nnamdi Azikiwe Library and on international evidence from Franco et al. and Bulunga and Thondhlana [27,31], libraries could develop carbon-literacy training for staff aligned with the broader institutional sustainability agenda. Student-led sustainability committees operating within library governance structures could serve as agents of peer influence, normalising energy-saving behaviours in ways that top-down directives alone are less likely to achieve.

4.4 Need for Stakeholder Participation

Decarbonisation in Nigerian university libraries is unlikely to be achieved through isolated technical interventions alone; it plausibly requires coordinated, sustained participation from a broad stakeholder community encompassing university management,

University Librarians, academic staff, students, facilities engineers, procurement officers, government agencies, and private-sector energy providers. Cross-departmental sustainability-officer mandates, library energy committees with student and non-academic staff representation, and inter-library consortia for shared procurement of renewable-energy equipment are mechanisms through which such participation could be structured and institutionalised. National bodies such as the Nigerian Library Association (NLA) could facilitate knowledge exchange, advocacy for policy reform, and capacity-building for library professionals in carbon management, consistent with the competency-based approach advocated by Mazhar et al. [26]. International partnerships with African university library networks and global bodies such as IFLA (International Federation of Library Associations and Institutions) could accelerate the transfer of decarbonisation knowledge and tools to the Nigerian context.

4.5 Addressing Carbon Lock-In and Long-Term Planning

Carbon lock-in as described by Worsham and Brecha has particular salience in the Nigerian university library context [10]. Breaking this cycle would plausibly require long-term capital planning to retire diesel generator capacity progressively in favour of renewable systems. This study's design does not include the equipment-age and condition data needed to test the feasibility of a specific replacement schedule directly; accordingly, the suggestion that university estates departments develop 10-year asset replacement plans for library generator stock, with phased diesel-reduction targets, is presented here as a logical implication of the carbon lock-in framework and the barrier rankings in Table 5, rather than as an empirical finding of this study. Such plans, where pursued, could usefully be linked to university-level carbon-neutrality commitments under the Paris Agreement and Nigeria's NDCs, situating the library within a broader institutional decarbonisation narrative.

5. Conclusions

This study presents a comparative analysis of estimated carbon emissions in 24 Nigerian university libraries across six geopolitical zones. The findings indicate that diesel-powered generators are the dominant source of estimated GHG emissions in the sampled libraries, accounting for an estimated 42-68% of total annual emissions; that descriptively large inter-zonal variation exists, with North-East zone libraries showing per capita CO_{2e} estimates up to roughly 2.6 times those of South-West zone libraries; and that respondents perceived institutional and financial barriers — rather than technical constraints or market failures — as the principal bottleneck to decarbonisation.

The findings are also consistent with the possibility that a combination of renewable-energy investment, demand-side management, LED lighting retrofit, and governance reform could meaningfully reduce library carbon emissions in Nigeria, provided adequate capital

mechanisms — most plausibly through TETFund and international development finance — are mobilised; because no counterfactual or before-and-after intervention design was applied in this study, this should be read as a plausible pathway supported by descriptive and institutionally reported evidence rather than as a demonstrated causal effect. The two solar installations identified in the South-West zone, and the LED retrofit programme at Ahmadu Bello University, offer illustrative, self-reported examples of the kind of intervention that appears promising in this setting; independent, metered verification of their reported savings would strengthen this evidence base and is recommended as a priority for future research.

The novelty of this paper lies in its geopolitical zone-comparative framework, which suggests that nationally averaged data may mask substantial structural inequalities between Nigerian regions. Decarbonisation strategies well suited to the relatively grid-connected South-West may be considerably less effective in the North-East without first addressing fundamental infrastructure deficits. If corroborated by further research, this would have implications for national policy design, suggesting that a one-size-fits-all approach may be insufficient and that geopolitically differentiated investment priorities merit consideration.

This study has several limitations, which should be read alongside the methodological clarifications provided in Sections 2 and 3. The 24 sampled libraries were purposively — not randomly — selected on the basis of accessible energy records and administrator willingness to participate; while the sample spans all six geopolitical zones, it does not permit statistically generalisable claims about the full population of Nigerian university libraries, and the absence of a documented sampling frame (Section 2.2) means the extent of selection bias cannot be precisely quantified. Reliance on self-reported fuel and electricity consumption data, in the absence of independent metering at most surveyed facilities, introduces measurement uncertainty that this study has not attempted to bound statistically. Library-level activity data, per-library totals by scope, and post-hoc pairwise statistical comparisons are not reported here (Section 2.5); the authors recommend that an anonymised library-level dataset be made available as supplementary material in any subsequent publication drawing on this dataset, to allow independent reproduction of the estimates in Tables 3 and 4. Future research should also develop and validate standardised energy-monitoring protocols for Nigerian academic libraries, establish longitudinal databases of library-level GHG inventories, and evaluate the emission-reduction impact of specific interventions such as solar PV and LED retrofitting through quasi-experimental or metered before-and-after designs.

Subject to these limitations, the findings suggest that Nigerian university libraries have the potential to contribute to broader institutional decarbonisation in African higher education by developing context-specific policy and standards, working to reduce their carbon

footprint, and acting as sites of sustainability learning and advocacy for institutional and national policy reform. Realising this potential, and confirming the extent to which it holds beyond the present sample, would allow Nigerian library professionals to contribute more confidently to the country's climate commitments and to the global pursuit of Sustainable Development Goal 13 on Climate Action.

6. Abbreviations

AHP: Analytical hierarchy process
BTU: British thermal units
CF: Carbon footprint
DSM: Demand-side management
EIQ: Energy-inventory questionnaire
GHG: Greenhouse gas
GSM: Gross square metres
HEI: Higher education institution
HVAC: Heating, ventilation, and air conditioning
IFLA: International Federation of Library Associations and Institutions
IPCC: Intergovernmental Panel on Climate Change
ISO: International Organization for Standardization
IT: Information technology
kVA: Kilovolt-amperes
kWp: Kilowatts peak (photovoltaic)
LED: Light-emitting diode
NDC: Nationally Determined Contribution
NLA: Nigerian Library Association
NUC: National Universities Commission
NERC: Nigerian Electricity Regulatory Commission
OECD: Organisation for Economic Co-operation and Development
PV: Photovoltaic
RQ: Research question
SDG: Sustainable Development Goal
tCO₂e: Tonnes of carbon dioxide equivalent
TETFund: Tertiary Education Trust Fund

7. Declarations

7.1 Acknowledgements

The authors express sincere gratitude to the University Librarians, Deputy University Librarians, and officers of all 24 university libraries who participated in this study and who generously provided access to energy consumption records, facility plans, and institutional data. Special acknowledgement is extended to: Mr. Emeka

Nwosu and Mrs. Chioma Okafor (Nnamdi Azikiwe Library, UNN); Dr. Hauwa Usman and Mallam Aminu Musa (Kashim Ibrahim Library, ABU Zaria); Dr. Grace Adeyemi and Mr. Biodun Ogundimu (Kenneth Dike Library, University of Ibadan); Mr. Ofonime Bassey and Mrs. Ngozi Ekwueme (J.D. Horsfall Library, UNIPORT); Mr. Ahmed Bukar and Mrs. Fanna Musa (University of Maiduguri Central Library); Dr. Sunmola Olawale and Mr. Tobi Ajayi (Hezekiah Oluwasanmi Library, OAU); Mr. Chinedu Alozie and Mrs. Peace Ikenna (FUTO Library); Mr. Mustapha Garba and Dr. Abubakar Sani (ATBU Bauchi Library); Mrs. Zainab Musa and Mr. Ibrahim Yakubu (Gombe State University Library); Mrs. Rebecca Longwap and Mr. Amos Dashe (University of Jos Library); Mr. Sola Adeniyi and Mrs. Kehinde Olusanya (Lagos State University Library); Mrs. Nneka Chukwu and Mr. Obinna Eze (ESUT Library); Mr. Samuel Uwa and Mrs. Blessing Akpan (Rivers State University Library); and all other staff members at each institution who facilitated data collection. The authors also acknowledge the support of the Nigerian Library Association (NLA) for facilitating institutional introductions, and of the Tertiary Education Trust Fund (TETFund) for its broader commitment to sustainable development in Nigerian higher education.

7.2 Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

7.3 AI Statement

During the preparation of this work the author used ChatGPT 4.0 and Grammarly to perform copyediting and language corrections on this manuscript. After using these tools, the authors reviewed, verified, and edited the content as needed, and maintain full accountability for the final text and the accuracy of the publication.

7.4 Competing Interests

The authors declare no competing interests.

7.5 Data Availability

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request. In line with the recommendation in Section 5, the authors intend to make an anonymised, library-level version of the dataset available as supplementary material to support independent verification of the estimates reported in Tables 3 and 4.

7.6 Author Contributions

K.S.J.D.: conceptualisation, methodology, writing—original draft, supervision, data collection (South-South and North-East zones), writing—review and editing. R.O.Q.: data collection (North-West zone), writing—review. K.S.J.D. & R.O.Q.: data collection (South-West

zone), data analysis, writing—review. R.O.Q.: data collection (South-West zone, secondary sites), writing—review. K.S.J.D.: data collection (South-East zone), writing—review. All authors reviewed and approved the final manuscript.

7.7 Figures

This manuscript includes four figures (Figures 1-4), placed at the relevant points in the main text (Sections 2.4, 3.2, and 3.3), illustrating the emission-factor summary, the category-level emission estimates, the zonal per-capita comparisons, and the barrier rankings reported in Tables 2-5. The authors confirm that all four figures are original, were generated directly by the authors from the study's own data, and do not reproduce any third-party copyrighted material; each figure caption includes a copyright statement (© 2026 the authors) accordingly. High-resolution (300 DPI) JPG versions of each figure have been uploaded separately to the editorial office as required.

7.8 Ethics Approval and Consent to Participate

Ethical approval was obtained from the Federal University of Education, Zaria Institutional Review Board (Ref: FUEZ/IRB/2025/TECETEL/RES/023) of the participating universities prior to data collection, as noted in Section 2.2. All participating University Librarians, deputies, and other respondents provided informed consent before completing the survey instruments, and institutional data (electricity bills, fuel records) were shared only with the express approval of the relevant university authorities. All participants provided informed consent prior to participation. Respondents were assured of anonymity and the right to withdraw at any stage.

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