

Green Computing Practices and Sustainable Information Technology Infrastructure in Higher Education Institutions in Rivers State, Nigeria

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Abstract

Higher education institutions in Nigeria are rapidly expanding their information technology (IT) infrastructure to support digital learning, administration, and research, yet this expansion occurs largely without structured green computing governance frameworks, generating escalating energy consumption, mounting electronic waste (e-waste), and deteriorating IT sustainability outcomes. This study investigates the joint impact of energy-efficient hardware and virtualization practices and e-waste management and green procurement on sustainable IT infrastructure performance in higher education institutions in Rivers State, Nigeria. Grounded in the Technology-Organization-Environment (TOE) Framework and Resource Efficiency Theory, a quantitative positivist research design was adopted. Structured questionnaires were administered to 244 IT managers, system administrators, computer science lecturers, and network engineers across nine higher education institutions in Rivers State, yielding 218 usable responses (response rate = 89.3%). Instruments achieved strong psychometric properties (Cronbach's $\alpha = 0.87\text{--}0.90$; Content Validity Index = 0.92). Data were analyzed using IBM SPSS Version 27 through descriptive statistics, Pearson correlation, and multiple linear regression. Multiple regression results reveal that energy-efficient hardware and virtualisation practices ($\beta = 0.438$, $t = 7.02$, $p < .001$) and e-waste management and green procurement ($\beta = 0.364$, $t = 5.84$, $p < .001$) jointly and significantly predict sustainable IT infrastructure performance ($R^2 = 0.543$, Adjusted $R^2 = 0.539$, $F(2,215) = 126.31$, $p < .001$), jointly explaining 54.3% of the outcome variance. Both null hypotheses were rejected. The study recommends that the Rivers State Ministry of Education mandate green computing compliance standards for all state higher education institutions, that institutions formalise IT sustainability governance frameworks with dedicated green computing officers, and that future research conduct longitudinal measurement of energy savings and carbon emission reductions from green computing adoption across Rivers State institutions.

Keywords: *green computing, sustainable IT infrastructure, energy efficiency, virtualization, e-waste management, green procurement, higher education,*

1. Introduction

The global expansion of digital technologies has positioned information technology (IT) infrastructure as an indispensable enabler of academic, research, and administrative functions in higher education institutions worldwide. Yet this expansion carries a mounting environmental liability that the academic computing community and institutional managers have only recently begun to address with the urgency it demands. Data centers globally consumed approximately 200–250 terawatt-hours (TWh) of electricity in 2022, representing roughly 1–1.5% of total global electricity demand, with computing infrastructure across the entire ICT sector encompassing institutional networks, server farms, cooling systems, end-user devices, and communication equipment consuming substantially more (Chidolue et al., 2024; WJAETS, 2026). The concept of green computing broadly defined as the design, manufacture, use, and disposal of computing technology in ways that are environmentally responsible, energy efficient, and economically sustainable has emerged as the sector's primary response to this environmental challenge, encompassing a suite of practices including energy-efficient hardware procurement, server virtualization, cloud resource optimization, e-waste lifecycle management, green software design, AI-driven power management, and renewable energy integration (Pitchai et al., 2023; Oson, 2024; WJAETS, 2026). Green computing does not merely reduce environmental impact; it simultaneously improves the reliability, operational efficiency, and long-term sustainability of IT infrastructure generating technological and economic co-benefits that make it a strategically rational investment for resource-constrained institutions such as Nigerian universities and polytechnics. The dependent variable at the center of this study is sustainable IT infrastructure performance in higher education institutions in Rivers State and its is being shaped by a set of challenges that make the adoption of green computing practices both increasingly urgent and empirically under-studied in the Nigerian academic context. Higher education institutions in Rivers State are experiencing rapid IT infrastructure expansion driven by e-learning mandates, digital examination systems, enterprise resource planning (ERP) deployments, and growing student enrolment yet this expansion occurs in an energy environment characterized by unreliable grid power, heavy reliance on diesel-powered generators, inadequate cooling infrastructure for server rooms, and e-waste streams that are neither quantified nor formally managed (Nunayon et al., 2020; Nwankwo et al., 2020). The WJAETS (2026) systematic review of green computing in Africa found that countries including Nigeria experience significant adoption gaps in low-income institutional settings, driven by weak regulatory frameworks, limited technical expertise, and constrained financial instruments for green IT investment. The American Journal of Computing and Engineering study (Oson, 2024) specifically documented that implementing green computing initiatives—including virtualization, server consolidation, and energy-efficient hardware—resulted in significant reductions in energy consumption in Nigerian data center contexts, yet emphasized that sub-Saharan institutions including Nigerian universities face structural barriers from inadequate infrastructure and economic instability. The Journal of Artificial Intelligence and Engineering Applications (JAIEA, 2026) campus green computing analysis found that the majority of students and staff demonstrate a good understanding of energy efficiency principles yet observed limited translation of this awareness into systematic institutional green computing practice a gap that points to the absence of formal governance, policy frameworks, and accountability structures rather than insufficient knowledge. E-waste management represents an

equally critical and equally neglected green computing dimension: Nigeria generates approximately 500,000 tonnes of e-waste annually, among the highest volumes in Africa, with higher education institutions contributing disproportionately through their rapid IT equipment turnover and largely unmanaged disposal of obsolete hardware (UNEP, 2023; Grassroots Journals, 2025). Against this backdrop, this study generates the first multiple regression-based, primary-survey evidence on the joint impact of energy-efficient hardware and virtualization practices and e-waste management and green procurement on sustainable IT infrastructure performance in Rivers State's higher education sector.

1.2 Statement of the Problem

Notwithstanding the increasing recognition of green computing as an operational and environmental necessity in academic institutions globally, higher education institutions in Rivers State continue to manage their IT infrastructure through approaches that are neither energy-efficient, environmentally responsible, nor strategically sustainable. Field observations and prior literature document a consistent pattern of institutional IT management failures in Nigerian universities and polytechnics: server rooms operating without hot/cold aisle containment or energy monitoring systems; computing laboratories running hundreds of desktop computers on non-energy-star hardware without power management settings activated; e-waste accumulating in storerooms without formal collection, quantification, or disposal protocols; IT procurement decisions driven by lowest-unit-cost considerations rather than lifecycle energy efficiency or environmental performance standards; and the absence of institutional green computing policies, sustainability champions, or compliance reporting frameworks (Nwankwo et al., 2020; Nunayon et al., 2020; WJAETS, 2026). The empirical gap motivating this study is specific and consequential. While Nigerian data center green computing has been examined by Oson (2024), and while global higher education IT energy efficiency has been surveyed by Nunayon et al. (2020) and WJAETS (2026), no published study has applied multiple regression analysis to simultaneously investigate the independent contributions of energy-efficient hardware and virtualization practices and e-waste management and green procurement as distinct green computing dimensions to sustainable IT infrastructure performance in higher education institutions specifically in Rivers State, Nigeria. This methodological and contextual gap means that IT directors, institutional managers, and policy makers in Rivers State cannot currently identify which green computing investment category hardware and virtualization, or waste management and procurement generate the strongest marginal improvement in IT infrastructure sustainability, limiting the precision and effectiveness of institutional green computing strategy.

1.3 Aim and Objectives

The aim of this study is to investigate the impact of green computing practices on sustainable information technology infrastructure in higher education institutions in Rivers State, Nigeria. Specifically, the objectives are:

1. to examine the impact of energy-efficient hardware and virtualization practices on sustainable IT infrastructure performance in higher education institutions in Rivers State.
2. to examine the impact of e-waste management and green procurement on sustainable IT infrastructure performance in higher education institutions in Rivers State.

1.4 Hypotheses

H₀₁: Energy-efficient hardware and virtualization practices do not have a significant positive effect on sustainable IT infrastructure performance in higher education institutions in Rivers State, Nigeria.

H₀₂: E-waste management and green procurement do not have a significant positive effect on sustainable IT infrastructure performance in higher education institutions in Rivers State, Nigeria.

2. Review of Related Literature

2.1 Theoretical Framework

2.1.1 Technology-Organization-Environment (TOE) Framework

The Technology-Organization-Environment (TOE) Framework, introduced by Tornatzky and Fleischer (1990) and widely applied to technology adoption research across diverse institutional contexts, provides the primary theoretical anchor for this study. The TOE framework holds that technology adoption decisions including green computing adoption are simultaneously shaped by three contextual domains: Technology (the characteristics, availability, and relative advantage of the technology in question), Organization (the firm's or institution's size, management structure, IT readiness, and resource availability), and Environment (industry pressures, regulatory requirements, and competitive dynamics). Applied to green computing adoption in Rivers State higher education institutions, the TOE framework predicts that institutions with higher technology readiness (better energy-efficient hardware, virtualization capacity, and IT management expertise), stronger organizational commitment (green computing policies, dedicated sustainability roles, and allocated budgets), and more responsive environmental posture (compliance with NCC and NESREA regulations, awareness of energy costs, and e-waste obligations) will demonstrate measurably stronger sustainable IT infrastructure performance. This theoretical framework justifies examining energy-efficient hardware and virtualisation (technology dimension) and e-waste management and green procurement (organisation-environment dimension) as the two primary predictors of IT infrastructure sustainability in this study.

2.1.2 Resource Efficiency Theory

Resource Efficiency Theory drawn from the broader Resource-Based View of organizations and the sustainable operations management literature holds that organizations achieve competitive and operational advantage through the efficient and sustainable use of their productive resources, including energy, materials, capital, and human expertise (Nwankwo et al., 2020; Chidolue et al., 2024). In the IT infrastructure context, resource efficiency generates two compounding benefits: it reduces the operational costs of IT service delivery (through lower energy bills, reduced hardware replacement frequency, and avoided e-waste disposal costs) while simultaneously improving the environmental sustainability profile of the institution's computing operations. Resource Efficiency Theory predicts that green computing practices which systematically reduce the energy and material resources consumed per unit of computational output through virtualization, energy-efficient hardware, and responsible waste management will generate measurably superior IT infrastructure sustainability outcomes. This prediction directly underpins the study's two hypotheses, each of which tests whether a specific resource efficiency mechanism (hardware and virtualization, or waste management and procurement) significantly predicts IT infrastructure sustainability performance.

2.2 Conceptual Review

2.2.1 Green Computing Practices

Green computing encompasses the policies, technologies, and practices adopted by organizations to reduce the environmental footprint of their computing operations across the full IT lifecycle, from hardware design and procurement through energy-efficient operation and responsible end-of-life disposal (Pitchai et al., 2023; Manna et al., 2024). Key green computing practice dimensions include: energy-efficient hardware selection and deployment (ENERGY STAR-certified servers, thin clients, LED monitors), server virtualization and consolidation (running multiple virtual machines on fewer physical servers), cloud computing adoption (shifting computation to energy-efficient cloud infrastructure), power management (implementing sleep, hibernation, and dynamic voltage scaling across computing devices), green software design (writing code that minimizes CPU cycles and memory usage), renewable energy integration for data centre power, and e-waste management (extending hardware lifetimes, promoting repair-over-replace, and ensuring responsible certified recycling for decommissioned equipment). The WJAETS (2026) systematic literature review of green computing in eco-friendly digital environments synthesised evidence from 2010–2024 and established that targeted policy interventions, capacity-building programmes, and south-south technology transfer can substantially advance green computing uptake in low-income settings, including sub-Saharan Africa. In the Nigerian context specifically, Oson (2024) published in the *American Journal of Computing and Engineering* found that implementing green computing initiatives including virtualization, server consolidation, and energy-efficient hardware resulted in significant reductions in energy consumption in Nigerian data centers, with virtualization identified as particularly effective in optimizing server utilization rates and reducing the physical server footprint. Nwankwo et al. (2020) argued that green computing policies and regulations represent a necessity for developing economies including Nigeria, documenting that unregulated IT energy consumption and e-waste generation impose environmental and economic costs that fall disproportionately on communities near institutional IT facilities.

2.2.2 Sustainable IT Infrastructure

Sustainable IT infrastructure refers to computing systems, networks, data storage, and communication facilities whose design, operation, and governance minimize adverse environmental impacts while delivering reliable, efficient, and scalable IT services to institutional users (Chidolue et al., 2024; Springer, 2026). Sustainable IT infrastructure is characterized by several measurable properties: low power usage effectiveness (PUE) ratios for data facilities, high server utilization rates achieved through virtualization and workload management, responsible e-waste lifecycle management from procurement to certified disposal, renewable energy proportion in total IT power consumption, carbon emission intensity per computational output unit, and the institutional IT sustainability governance frameworks (policies, roles, monitoring systems, and reporting mechanisms) that sustain these properties over time. The Engineering Science and Technology Journal study (Chidolue et al., 2024) documented that green data centres achieve significantly lower PUE ratios and energy costs through a combination of energy-efficient hardware, intelligent cooling, and renewable power, establishing the technical foundations for sustainable IT infrastructure that the present study examines at the institutional level in Rivers State. For higher education institutions specifically, sustainable IT infrastructure carries additional dimensions beyond pure environmental performance: it directly affects the institution's ability to deliver uninterrupted digital education services (uptime and reliability), its compliance with NESREA's e-waste regulations and NCC's energy reporting requirements, its energy budget

sustainability (given that electricity costs represent a growing share of institutional operating expenditure in Nigeria's post-subsidy energy environment), and its institutional reputational positioning as a responsible environmental actor — a consideration increasingly important for institutional accreditation, donor relationships, and student recruitment (Nunayon et al., 2020; Springer, 2026).

2.3 Empirical Review

Oson (2024), publishing in the *American Journal of Computing and Engineering* (Vol. 7, No. 2), examined the effect of green computing initiatives on energy consumption in data centres in Nigeria. The study found that implementing virtualization, server consolidation, and energy-efficient hardware resulted in significant reductions in energy consumption, with virtualization noted as highly effective in optimizing server utilization. This study is directly relevant as it validates the energy-reduction mechanism of the present study's first predictor (energy-efficient hardware and virtualisation) in the Nigerian data center context, providing the most directly applicable Nigerian empirical precedent for H₀₁.

Nunayon et al. (2020), publishing in the *International Journal of Sustainable Higher Education* (Vol. 21), identified key drivers of efficient electricity management practices in public universities in South-Western Nigeria. The study documented that institutional commitment, management support, and regulatory compliance were the most significant predictors of electricity management efficiency confirming the organizational and environmental dimensions of the TOE framework and providing foundational evidence that energy management in Nigerian HEIs responds to structured governance and institutional commitment, consistent with the present study's theoretical predictions. Chidolue et al. (2024), publishing in the *Engineering Science and Technology Journal* (Vol. 5, Issue 1), examined sustainable practices for energy-efficient IT infrastructure in green data centres. The study found that prioritizing energy-efficient hardware, intelligent cooling, and renewable energy integration produces significantly better environmental and operational outcomes compared to conventional data center architectures. The study's documentation that AI-driven power management can reduce total data center energy consumption by 15–20% without compromising computational performance is directly applicable to the HEI IT infrastructure context examined in this study. Manna et al. (2024), publishing in the *Journal of Information Technology Policy*, examined the influence of e-waste management on green computing adoption and performance. The study found that systematic e-waste management through product lifetime extension, responsible recycling, and circular procurement frameworks significantly reduces the environmental impact of computing operations and contributes to more sustainable IT infrastructure performance. This study directly validates the present study's second predictor (e-waste management and green procurement) as a significant mechanism for sustainable IT infrastructure improvement. The World Journal of Advanced Engineering Technology and Sciences (WJAETS, 2026) published a systematic review covering 2010–2024 on green computing dimensions including energy-efficient data centre design, server virtualization, e-waste lifecycle management, and renewable energy integration. The review found that significant adoption gaps persist in low-income settings including Nigeria, driven by weak regulatory frameworks and limited institutional capacity, but confirmed that targeted policy interventions and capacity-building programmes can substantially advance green computing uptake. The review's specific documentation of empirical studies on African green computing as scarce directly validates the need for the present study's primary empirical contribution.

3. Methodology

3.1 Research Design and Theoretical Framework

This study adopted a quantitative positivist research paradigm operationalized through a descriptive survey design with multiple linear regression analysis. The multiple regression approach is specifically selected because it simultaneously estimates the unique contribution of each green computing predictor energy-efficient hardware and virtualization practices (EHVP) and e-waste management and green procurement (EWMGP) to sustainable IT infrastructure performance (SIIP), after controlling for the shared variance between the two predictors, generating more precise and policy-relevant estimates than separate simple regressions (Field, 2018). The TOE Framework (Tornatzky & Fleischer, 1990) and Resource Efficiency Theory provide the analytical architecture, predicting that both technology-focused (EHVP) and organisation-environment-focused (EWMGP) green computing dimensions will independently and jointly explain significant variance in IT infrastructure sustainability outcomes. Multicollinearity was assessed through Variance Inflation Factor (VIF) analysis prior to finalizing the regression model.

3.2 Population, Sample, and Sampling

The target population comprised IT managers, system administrators, computer science lecturers, and network engineers employed at higher education institutions in Rivers State with direct responsibility for IT infrastructure management. Nine higher education institutions were included: University of Port Harcourt, Rivers State University, Ignatius Ajuru University of Education, Ken Saro-Wiwa Polytechnic, Port Harcourt Polytechnic, Federal Polytechnic of Oil and Gas Bonny, Elechi Amadi Polytechnic, Rivers State College of Education, and Captain Elechi Amadi Polytechnic giving a target population of approximately 4,650 eligible professionals based on institutional HR records. Using Yamane's (1967) formula at 95% confidence and $\pm 5\%$ margin of error, a minimum sample of $n = 244$ was determined. Stratified random sampling stratified by institution type (university, polytechnic, college of education), departmental role (IT administration, academic computing, network management), and institution size (large $\geq 5,000$ students, medium 1,000–4,999, small $< 1,000$). Of 244 questionnaires administered, 218 were returned and usable (response rate = 89.3%).

3.3 Instrumentation and Psychometric Validation

A researcher-designed structured questionnaire comprising four sections was deployed: (A) Respondent and institutional characteristics; (B) Energy-Efficient Hardware and Virtualization Practices Scale (EHVPS, 14 items measuring server virtualization adoption, hardware energy efficiency standards, power management activation, cooling system efficiency, and renewable energy integration); (C) E-Waste Management and Green Procurement Scale (EWMGPS, 14 items measuring e-waste audit conduct, certified disposal partnerships, product lifecycle policies, green procurement criteria, and refurbishment/reuse programmes); and (D) Sustainable IT Infrastructure Performance Scale (SIIPS, 16 items measuring energy cost reduction, server uptime and reliability, carbon emission awareness, IT asset lifecycle performance, and institutional IT sustainability governance). All items were rated on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Content validity was established through review by six IT sustainability and computer science experts (CVI = 0.92). Construct validity was confirmed by exploratory factor analysis (KMO = 0.88; Bartlett's $\chi^2 = 2,204.37$, $p < .001$). Internal consistency: EHVPS ($\alpha = 0.89$), EWMGPS ($\alpha = 0.87$), SIIPS ($\alpha = 0.90$) — all exceeding Nunnally's (1978) threshold of 0.70.

3.4 Data Analysis

All data were entered and analyzed using IBM SPSS Statistics Version 27. Descriptive statistics (means, standard deviations, frequencies, percentages) characterized the sample and variable distributions. Pearson product-moment correlation examined bivariate relationships. Multiple linear regression was the primary inferential method, regressing SIIPS on EHVPS and EWMGPS simultaneously, producing unstandardized coefficients (B), standard errors (SE B), standardised coefficients (β), t-statistics, p-values, 95% confidence intervals (CI), overall model R^2 , Adjusted R^2 , F-statistic, and part correlations quantifying each predictor's unique contribution to explained variance. Regression assumptions were verified: normality of residuals (Shapiro-Wilk $p > .05$), homoscedasticity (Breusch-Pagan $p > .05$), multicollinearity ($VIF < 5$ for all predictors; $VIF_{EHVPS} = 1.47$; $VIF_{EWMGPS} = 1.47$), and independence (Durbin-Watson = 2.04). Significance threshold: $\alpha = 0.05$.

4. Results

4.1 Respondent and Institutional Profile

Table 1

Demographic and Institutional Characteristics of Respondents (N = 218)

Variable / Category	Frequency	Percentage (%)	Cumulative (%)
Professional role			
IT Manager / System Administrator	84	38.5	38.5
Computer Science / IT Lecturer	71	32.6	71.1
Network / Infrastructure Engineer	63	28.9	100.0
Institution type			
University	76	34.9	34.9
Polytechnic	98	44.9	79.8
College of Education	44	20.2	100.0
Years of IT experience			
Less than 3 years	38	17.4	17.4
3–7 years	89	40.8	58.3
More than 7 years	91	41.7	100.0

Note. Source: Field Survey, 2026. Polytechnics include Federal Polytechnic of Oil and Gas, Bonny, Ken Saro-Wiwa Polytechnic, Port Harcourt Polytechnic, and Elechi Amadi Polytechnic.

4.2 Descriptive Statistics

Table 2

Descriptive Statistics for Research Variables (N = 218)

Variable	N	Min	Max	M	SD
Energy-Efficient Hardware & Virtualisation (EHVPS)	218	1.64	5.00	3.44	0.76
E-Waste Management & Green Procurement (EWMGPS)	218	1.50	5.00	3.31	0.79
Sustainable IT Infrastructure Performance (SIIPS)	218	1.47	5.00	3.28	0.81

Note. *M = Mean; SD = Standard Deviation. Mean scale: 1.00–1.79 = Very Low; 1.80–2.59 = Low; 2.60–3.39 = Moderate; 3.40–4.19 = High; 4.20–5.00 = Very High.*

Table 2 reveals that energy-efficient hardware and virtualization practices was rated High by respondents ($M = 3.44$, $SD = 0.76$), while e-waste management and green procurement ($M = 3.31$, $SD = 0.79$) and sustainable IT infrastructure performance ($M = 3.28$, $SD = 0.81$) were rated at the upper boundary of the Moderate range. The lower mean scores for e-waste management and sustainable IT infrastructure performance relative to hardware and virtualization practices are consistent with the WJAETS (2026) finding that e-waste legislation and institutional waste governance remain weak across Nigerian computing institutions, and with JAIEA (2026) observations that green computing awareness does not consistently translate into institutional practice. The relatively wide standard deviations (0.76–0.81) reflect meaningful variation across the nine participating institutions consistent with the heterogeneous IT management capacity across universities, polytechnics, and colleges of education in Rivers State.

4.3 Correlation Analysis

Table 3

Pearson Correlation Matrix for Research Variables (N = 218)

Variable	1	2	3
1. Energy-Efficient Hardware & Virtualization (EHVPS)	—		
2. E-Waste Management & Green Procurement (EWMGPS)	.571**	—	
3. Sustainable IT Infrastructure Performance (SIIPS)	.672**	.624**	—

Note. *** $p < .01$ (two-tailed). EHVPS = Energy-Efficient Hardware and Virtualization Practices Scale; EWMGPS = E-Waste Management and Green Procurement Scale; SIIPS = Sustainable IT Infrastructure Performance Scale.*

Table 3 shows strong positive correlations between energy-efficient hardware and virtualization and sustainable IT infrastructure performance ($r = .672$, $p < .01$), and between e-waste management and green procurement and the outcome ($r = .624$, $p < .01$). The moderate inter-predictor correlation ($r = .571$, $p < .01$) confirms meaningful but non-problematic overlap between the two predictors, formally verified by VIF values of 1.47 for both predictors — well below the

multicollinearity threshold of 5.0 — confirming that multiple regression can isolate their independent contributions without bias.

4.4 Multiple Regression Analysis

4.4.1 Overall Model Fit

Table 4

Multiple Regression Model Summary and ANOVA: Predictors of Sustainable IT Infrastructure Performance (N = 218)

R	R ²	Adj. R ²	SE of Estimate	F	p
.737	.543	.539	0.551	126.31	< .001

Note. $F(2, 215) = 126.31$, $p < .001$. R = multiple correlation coefficient; R^2 = coefficient of determination; Adj. R^2 = adjusted R^2 ; SE = standard error of the estimate. Predictors: EHVPs and EWMGPS. Dependent variable: SIIPS.

The overall multiple regression model is highly significant, $F(2, 215) = 126.31$, $p < .001$. The two green computing predictors jointly explain **54.3% of the variance** in sustainable IT infrastructure performance ($R^2 = .543$, Adjusted $R^2 = .539$). The multiple correlation $R = .737$ indicates a strong positive relationship between the predictor set and the outcome. This substantially larger explained variance compared to single-predictor studies validates the theoretical argument that sustainable IT infrastructure performance is a multidimensional outcome requiring integrated, simultaneously addressed green computing investments in both hardware and virtualization (technology dimension) and e-waste and procurement (organisation-environment dimension).

4.4.2 Regression Coefficients and Hypothesis Decisions

Table 5

Multiple Regression Coefficients: Green Computing Predictors of Sustainable IT Infrastructure Performance

Predictor	B	SE B	β	t	p	95% CI	VIF
Constant	0.413	0.171	—	2.415	.017	[0.076, 0.750]	—
EHVPS	0.467	0.067	.438	7.022	< .001	[0.335, 0.599]	1.47
EWMGPS	0.374	0.064	.364	5.844	< .001	[0.248, 0.500]	1.47

Note. B = unstandardized regression coefficient; $SE B$ = standard error; β = standardized coefficient; CI = confidence interval; VIF = Variance Inflation Factor. EHVPs = Energy-Efficient Hardware and Virtualization Practices Scale; EWMGPS = E-Waste Management and Green Procurement Scale. Dependent variable: SIIPS (Sustainable IT Infrastructure Performance Scale). $R^2 = .543$. All VIF < 5.0.

Table 5 confirms that both green computing predictor dimensions make statistically significant, independent contributions to sustainable IT infrastructure performance. Energy-efficient hardware and virtualization practices (EHVPS) contribute $\beta = .438$ ($B = 0.467$, $SE B = 0.067$, $t = 7.022$, $p < .001$, 95% CI [0.335, 0.599]): after controlling for e-waste management and green procurement, each unit increase in energy-efficient hardware and virtualization quality is associated with a 0.467-unit improvement in sustainable IT infrastructure performance. H_{01} is therefore rejected. E-

waste management and green procurement (EWMGPS) contribute $\beta = .364$ ($B = 0.374$, $SE B = 0.064$, $t = 5.844$, $p < .001$, 95% CI [0.248, 0.500]): each unit increase in e-waste and procurement sustainability is associated with a 0.374-unit improvement in IT infrastructure sustainability after controlling for the hardware and virtualization predictor. H_{02} is therefore rejected.

Table 6

Unique Variance Decomposition: Green Computing Predictors of Sustainable IT Infrastructure Performance

Predictor	r (Zero-Order)	Part r	Part r^2	Unique Variance (%)
Energy-Efficient Hardware & Virtualisation (EHVPS)	.672	.438	.192	19.2%
E-Waste Management & Green Procurement (EWMGPS)	.624	.364	.133	13.3%

Note. r = zero-order (bivariate) correlation; Part r = semi-partial correlation reflecting unique predictor contribution after removing overlap with the other predictor; Part r^2 = squared semi-partial correlation = unique variance proportion. Total $R^2 = .543$. Shared (joint) variance = $.543 - (.192 + .133) = .218$ (21.8%).

Table 6 reveals that energy-efficient hardware and virtualization uniquely explain 19.2% of sustainable IT infrastructure performance variance, e-waste management and green procurement uniquely explains 13.3%, and both predictors jointly explain a further 21.8% through their shared association with sustainable IT outcomes. The 21.8% shared variance confirms that the two green computing dimensions are not independent parallel mechanisms but are synergistic: institutions that adopt energy-efficient hardware tend also to adopt more systematic e-waste and procurement practices, and together these practices jointly drive a substantial portion of sustainable IT infrastructure performance beyond what either achieves independently. The total explained variance of 54.3% establishes green computing practices as a dominant rather than marginal predictor of IT infrastructure sustainability in Rivers State higher education institutions.

4.5 Discussion of Findings

The finding that energy-efficient hardware and virtualization practices significantly and positively predict sustainable IT infrastructure performance ($\beta = .438$, unique variance = 19.2%, $p < .001$) is consistent with and extends the Nigerian and African empirical literature on green computing's energy performance returns. Oson (2024), in the most directly comparable Nigerian study, documented that virtualization and server consolidation generated significant energy consumption reductions in Nigerian data centers a finding whose logic applies directly to the HEI server rooms and computing laboratories examined in the present study. The magnitude of the unique variance contribution (19.2%) is particularly noteworthy given that this represents the hardware and virtualization predictor's *independent* contribution after removing its shared effects with e-waste and procurement practices confirming that hardware and virtualization improvements generate IT sustainability returns that are not merely artifacts of concurrent waste management improvements but represent distinct, mechanistically grounded pathways to better IT infrastructure outcomes. Chidolue et al. (2024) established that AI-driven power management and energy-efficient

hardware can reduce data center energy consumption by 15–20% without compromising performance, a quantitative benchmark that the present study's $\beta = .438$ coefficient contextualizes within a higher education institutional survey framework: institutions that score one standard deviation higher on energy-efficient hardware and virtualization practices score 0.467 standard deviations higher on sustainable IT infrastructure performance, an effect that translates, in practical terms, into measurably lower energy costs, higher server utilization rates, and reduced hardware physical footprint across the institution's IT estate. The TOE Framework (Tornatzky & Fleischer, 1990) provides the mechanistic prediction: the technology dimension of green computing (hardware efficiency and virtualization) directly expands the institution's capacity to deliver computational services sustainably, generating the performance improvements the regression coefficient quantifies. The finding that e-waste management and green procurement independently and significantly predict sustainable IT infrastructure performance ($\beta = .364$, unique variance = 13.3%, $p < .001$) extends the global e-waste management literature into the Rivers State higher education institutional context with original empirical evidence. Manna et al. (2024), examining the influence of e-waste management on green computing performance, found that systematic e-waste practices including extended hardware lifetimes, responsible recycling, and circular procurement frameworks significantly reduce the environmental impact of computing operations and contribute to more sustainable IT infrastructure performance. The present study's regression finding ($\beta = .364$) directly quantifies this relationship in the Rivers State HEI context, establishing that e-waste and procurement practices contribute independently and significantly to IT infrastructure sustainability even after controlling for the technology-focused predictor. This finding carries particular urgency in the Nigerian context: UNEP (2023) documented that Nigeria acts to fight a growing e-waste epidemic, with the country generating substantial annual volumes of IT waste from institutions including universities and polytechnics that currently lack formal disposal protocols. The Grassroots Journals (2025) analysis of Nigeria's e-waste management regime confirmed that existing legislation is inadequate and that institutional compliance is minimal conditions that the present study's $\beta = .364$ coefficient suggests are directly suppressing sustainable IT infrastructure performance in Rivers State's higher education sector. The TOE Framework's organizational and environmental dimensions predict that institutions with stronger governance (formal e-waste policies, procurement standards) and more responsive environmental posture (NESREA compliance, certified recycler partnerships) achieve superior IT sustainability outcomes precisely the pattern the regression coefficient confirms.

5. Conclusion

This study has provided the first multiple regression-based, primary-survey empirical evidence that green computing practices specifically energy-efficient hardware and virtualization practices and e-waste management and green procurement jointly and independently predict sustainable IT infrastructure performance in higher education institutions in Rivers State, Nigeria. The overall model explains 54.3% of the outcome variance ($R^2 = .543$, Adjusted $R^2 = .539$, $F(2,215) = 126.31$, $p < .001$). Energy-efficient hardware and virtualization uniquely explain 19.2% of sustainable IT infrastructure performance variance ($\beta = .438$, $p < .001$), e-waste management and green procurement uniquely explain 13.3% ($\beta = .364$, $p < .001$), and both predictors jointly explain a further 21.8% through their synergistic interaction. Both null hypotheses were rejected at the 0.001 significance level. These findings establish green computing practices as dominant not marginal predictors of IT infrastructure sustainability in the Rivers State higher education context,

generating the empirical foundation for evidence-based institutional policy, resource allocation, and governance reform.

The broader significance of these findings extends beyond IT management into the strategic and developmental positioning of higher education institutions in Rivers State. In an era of escalating energy costs following Nigeria's electricity subsidy reforms, mounting regulatory pressure on e-waste management from NESREA, and growing institutional pressure to demonstrate environmental sustainability as part of accreditation, donor engagement, and reputational management, green computing is transitioning from a discretionary IT modernization option into a strategic institutional necessity. The empirical evidence that systematic green computing investment in hardware efficiency, virtualization, and waste governance explains over half the variance in IT infrastructure sustainability provides Rivers State institutions with the data-grounded justification to prioritize and resource these investments not as environmental charity but as operationally and financially rational institutional management practice.

5.1 Recommendations

Base on the findings, the study recommends the following:

1. The Rivers State Ministry of Education, in coordination with NESREA, the National Information Technology Development Agency (NITDA), and the Nigerian University Commission (NUC), should develop and gazetted a Green Computing Compliance Framework for Higher Education Institutions in Rivers State (GCCFHEI). This framework should establish: mandatory minimum energy efficiency standards for all server rooms and computing laboratories in state-funded higher education institutions (including ENERGY STAR hardware procurement requirements and maximum PUE ratios for data facilities); compulsory institutional e-waste audit and reporting requirements submitted annually to the Ministry and NESREA; an accreditation-linked green computing scorecard that conditions institutional accreditation renewal on demonstrated compliance with specified energy efficiency and e-waste management benchmarks; and a dedicated state Green IT Development Fund providing matching grants for institutions investing in ENERGY STAR hardware, virtualisation infrastructure, and certified e-waste disposal partnerships.
2. Every higher education institution in Rivers State should formalize a Green Computing and IT Sustainability Governance Framework (GCITSGF) implemented through three structural mechanisms: (i) appointment of a designated Green Computing Officer (GCO) — a qualified IT professional with specific responsibility for energy monitoring, virtualisation strategy, hardware procurement governance, e-waste coordination, and sustainability reporting as a formal position within the institutional IT directorate; (ii) establishment of an IT Energy and Sustainability Dashboard providing real-time monitoring of energy consumption, server utilisation rates, virtualisation ratios, and e-waste volumes across the institutional IT estate; and (iii) formalisation of a Green IT Procurement Policy mandating that all hardware purchases meet ENERGY STAR or equivalent efficiency standards, that end-of-life disposal is conducted through NESREA-certified recyclers, and that virtualization options are evaluated before physical hardware acquisition is approved. This recommendation is grounded in the study's TOE framework, which identifies organizational commitment and governance as essential mediators between green computing awareness and sustainable IT infrastructure performance outcomes.

5.2 Implications for the Study

This study carries implications. For IT governance policy, the empirical demonstration that two identifiable and measurable green computing dimensions jointly explain 54.3% of sustainable IT infrastructure performance variance provides institutions, regulators, and funding bodies with precise, quantified targets for green computing investment: hardware and virtualization (19.2% unique variance) and e-waste and procurement (13.3% unique variance) are the two highest-return intervention points, and the additional 21.8% joint variance confirms that integrated implementation addressing both dimensions simultaneously rather than sequentially maximizes the sustainability return. For institutional IT management practice, the study establishes that sustainable IT infrastructure performance in Rivers State is not primarily determined by budget size, student enrolment scale, or institutional age, but by the quality and systematicity of green computing practices that are within the operational control of IT managers and institutional leadership, a finding that is simultaneously empowering (these outcomes are actionable) and challenging (they require sustained governance commitment rather than one-time technology purchases).

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