

Development and Evaluation of a Web-Based Green ICT Management Application for Monitoring and Reducing Digital Ecological Footprint

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ABSTRACT

The rapid expansion of Information and Communication Technology (ICT) has contributed significantly to Nigeria's digital transformation while increasing concerns about energy consumption, carbon emissions and electronic waste. This study developed and evaluated a web-based Green ICT Management Application for monitoring and reducing Nigeria's digital ecological footprint. A Waterfall model methodology was adopted, comprising requirements analysis, system design, implementation, testing, and maintenance. The application was developed using HTML, PHP, and MySQL, with Xampp used as the local development and testing environment. The system integrates ICT data collection, energy-consumption assessment, carbon-emission estimation, e-waste, Digital Ecological Footprint calculation, and Green ICT recommendations. System acceptance and usage was assessed using the Unified Theory of Acceptance and Use of Technology (UTAUT) among 30 respondents. Results showed high acceptance across all constructs, with Behavioural Intention recording the highest mean score ($M = 4.11$), followed by Facilitating Conditions ($M = 4.09$), Effort Expectancy ($M = 4.08$), Social Influence ($M = 3.91$), and Performance Expectancy ($M = 3.83$). Pearson correlation analysis revealed significant positive relationships among all UTAUT constructs. The study concludes that the developed application will provide a feasible digital platform for monitoring ICT-related environmental impacts and supporting Green ICT decision-making in Nigeria.

Keywords: Digitalization, Ecological Footprint, Green ICT, Unified Theory of Acceptance and Use of Technology, Web-Based Application.

INTRODUCTION

The digital economy is intrinsically linked to information and communication technology (ICT), with ICT serving as the backbone for digital economic growth and transformation. More specifically, ICT refers to the set of technologies that can be digitalized. They include the technologies that allow the storage, the transmission, and the processing of information. Digitization refers to the changing process from analog to digital form. Digital development can indirectly affect the green total productivity factor through human capital accumulation and industrial structure upgrading (Hubert & Texier, 2025). The study's illustration of the impact of digitalization on green productivity factor is depicted in figure 1.



Figure 1: Impact of Digitalization on Green Productivity Factor (Hubert & Texier, 2025).

Nigeria's rapid technological growth, particularly in sectors like energy, digital software and hardware production, automation, manufacturing, telecommunications, e-commerce, and logistics, has significantly contributed to its greenhouse gas (GHG) emissions. Telecommunications infrastructure alone emits approximately 4,000 tonnes of CO₂ daily due to its reliance on diesel generators for powering base transceiver stations (BTS) and data centers (Olanrewaju et al., 2025).

Digital technologies have become indispensable drivers of socio-economic development in Nigeria. However, the environmental consequences associated with digital activities remain largely overlooked. (Tukur, Abdullahi & Abdulmalik, 2026) demonstrated that awareness of digital carbon footprints among Nigerians is relatively low despite substantial engagement with internet-based services. The study assessed the level of awareness of digital carbon footprints among Nigerians and estimated carbon dioxide (CO₂) emissions associated with common digital activities. A descriptive research design incorporating quantitative and qualitative approaches was adopted. Data were collected from 500 internet users across major Nigerian cities, including Lagos, Abuja, Port Harcourt, Kano, and Enugu, using structured online questionnaires. Results revealed relatively low awareness of digital carbon footprints, with only 48.4% of respondents indicating awareness, while 51.6% lacked knowledge of the environmental consequences of digital technologies. The findings revealed a substantial knowledge gap regarding the environmental implications of digitalization despite increasing internet penetration in Nigeria. The study recommended best practice such as green ICT monitoring investments,

The analysis by (Olanrewaju et al., 2025) synthesized peer-reviewed literature, national policies, and global best practices to highlight Nigeria's reliance on fossil fuels, inadequate regulatory frameworks, and the limited integration of renewable energy in ICT operations. Comparative insights from South Africa, Brazil, and India done by the study revealed gaps in Nigeria's sustainability strategies and policy enforcement. Findings indicated that weak emission reporting systems, inefficient e-waste management, and a lack of green technology incentives exacerbate environmental risks. The study underscored the need for targeted interventions, such as carbon taxation, enhanced regulatory enforcement, and incentives for renewable energy adoption in the ICT sector.

In Nigeria, digital transformation is capable of reducing emissions through energy efficiency, the adoption low-emission technologies, and the creation of new market opportunities. However, it raises sustainability concerns such as the use of rare material, inequalities in technology access, and employment opportunities. It intersects with global environmental challenges like climate change, waste management and environmental pollution. Thus, (Odiche & Akeem, 2024) reviewed issues and challenges hindering digital transformation in achieving multiple SDGs, focusing on Nigeria. The study recommended strategic digital frameworks prioritizing inclusivity and sustainability towards reshaping Nigeria's approach to achieving the UNSDGs.

Achieving sustainability in today's society requires the search for innovative tools that focus on using resources in such a way that they are not depleted. (Borissova et al., 2025) offered a web-based application

to support decision-making in determining the progress of the green transition. In a related study, (Priyana et al., 2025) addressed the challenge of limited access to cocoa cultivation information faced by the Sari Merta Cocoa Farmers Group. It introduced a Green Information Technology (Green IT)-based website as a sustainable digital solution. To assess system effectiveness, a User Acceptance Test (UAT) was conducted with 24 respondents, focusing on scenarios involving homepage access, menu navigation, information retrieval, feature functionality, and efficiency. The study employed WordPress CMS and the Elementor plugin to provide user-friendly management and efficient content delivery. The results showed consistently high acceptance, with all indicators scoring above 4.3 and acceptance levels exceeding 85%. Specifically, website appearance (94.2%), usefulness (94.2%), menu functionality (91.7%), time efficiency (92.5%), fulfilment of user needs (90.8%), and support for learning cocoa varieties (90.0%) demonstrated very strong performance. Meanwhile, ease of menu navigation (87.5%) and ease of finding information (85.8%) were slightly lower but still categorized as good.

(Ramos et al., 2026) in a similar study aimed to identify the factors influencing aesthetic visitors' continuance usage intention of websites and social media as digital marketing tools. Based on the technology acceptance model, four constructs were included: perceived ease of use, perceived usefulness, website quality and social media. Results indicated that perceived usefulness, website quality, and social media significantly and positively influenced continuance usage intention, while perceived ease of use did not show a significant effect. Website quality emerged as the strongest predictor, followed by social media, underscoring the critical role of technological design and social interaction in shaping digital marketing adoption. The study contributes to theory by extending TAM with context-specific constructs in the aesthetic tourism sector, a context where technology adoption remains underexplored.

Existing literature has shown that awareness of digital carbon footprints among Nigerians is relatively low despite substantial engagement with internet-based services (Tukur, Abdullahi & Abdulmalik, 2026). Gaps in Nigeria's sustainability strategies and policy enforcement tend towards weak emission reporting systems, inefficient e-waste management, and a lack of green technology incentives exacerbate environmental risks (Olanrewaju et al., 2025). The aim of this study is to develop and evaluate a web-based green ICT management application for monitoring and reducing Nigeria's digital ecological footprint. The study contributes to knowledge by developing and evaluating a context-specific web-based framework for quantifying, monitoring, and reducing Nigeria's digital ecological footprint, integrating ICT energy consumption, carbon emissions, e-waste, resource use, and green ICT decision-making into a unified digital management platform while supporting sustainable digital transformation, climate resilience, policymaking, and future research in Nigeria.

METHOD

The study adopted a waterfall model approach which involves design-and-development method to develop and evaluate a web-based Green ICT Management Application for monitoring and reducing Nigeria's digital ecological footprint. The waterfall model consists of five stages: Requirement Analysis, System Design, Implementation, Testing and Maintenance as depicted in figure 2. The application was developed using HTML, PHP, and MySQL, with WAMP serving as the local development and testing environment. The system was designed as a web-based platform comprising modules for ICT data collection, energy-consumption assessment, carbon-emission estimation, e-waste and resource assessment, digital ecological-footprint calculation, and Green ICT recommendations. Users enter relevant ICT information, including energy use, device utilization, equipment lifespan, electronic waste generation, and other resource-consumption indicators, after which the application processes the data and presents ecological-footprint indicators and recommendations through a web-based dashboard.

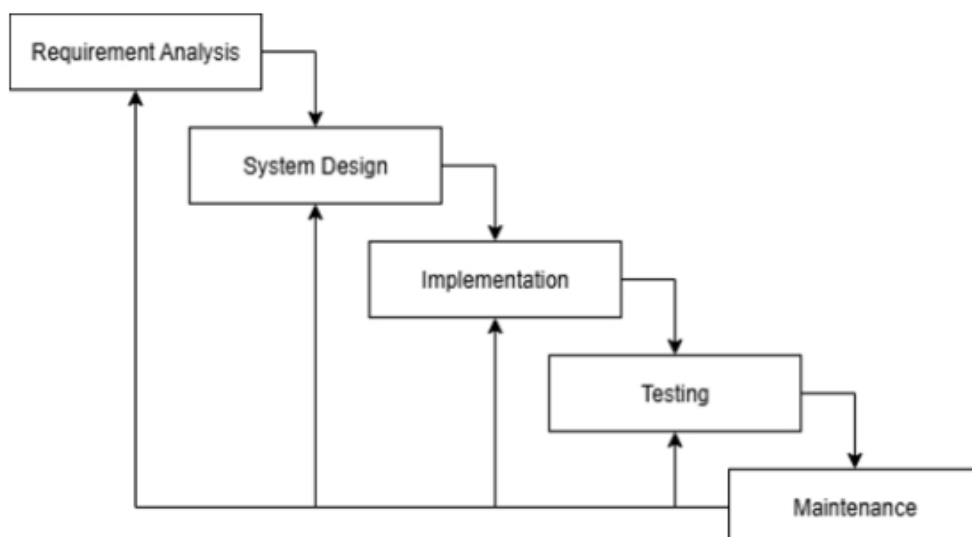


Figure 2: Waterfall Model (Priyana et al., 2025)

Stage One: ICT Data Collection

This stage is the ICT Data Collection Layer, which serves as the primary input to the system. Users enter information about ICT equipment and its usage patterns through web-based forms. The purpose of this stage is to establish a reliable database of ICT activities from which subsequent environmental calculations can be performed.

The information may be entered include:

- ICT equipment type
- Device name
- Number of devices
- Power rating in watts
- Average hours of use per day
- Number of operating days per month
- Equipment lifespan
- Estimated e-waste weight
- Equipment utilization information

Stage Two: Energy Assessment

$$E = \frac{P \times Q \times H \times D}{1000} \quad (1)$$

Here

EE = energy consumption in kWh/month

PP = power rating in watts

QQ = quantity of equipment

HH = hours of operation per day

DD = operating days per month

Stage Three: Carbon Estimation

The third component converts electricity consumption into an estimated carbon-emission value. The emission factor will be stored as a configurable parameter rather than permanently embedded in the PHP code. This will allow the researcher or administrator to update the factor when a more appropriate Nigerian or study-specific value becomes available. The module therefore provides an estimate of the carbon impact associated with the electricity consumed by the ICT infrastructure.

The relationship is calculated as:

$$CO_2 = E \times EF \quad (2)$$

here

- CO_2 represents estimated carbon emissions
- EE represents electricity consumption
- EF represents applicable electricity-emission facto

Stage Four: E-Waste Assessment

The fourth stage evaluates the material and resource consequences of ICT equipment. For example, equipment with a short lifespan and high replacement frequency may generate greater e-waste pressure than equipment that remains operational for a longer period.

The application considers variables such as:

- Equipment quantity
- Equipment lifespan
- Replacement frequency
- Estimated equipment mass
- E-waste generated
- Reuse potential
- Refurbishment potential

The calculation for an estimated e-waste burden is:

$$W = \sum_{i=1}^n QI \times Mi \times Ri \quad (3)$$

Stage Five: Digital Ecological Footprint Assessment

The fifth stage integrates the environmental indicators generated by the preceding modules. Instead of considering energy, carbon and e-waste independently, the application produces an integrated Digital Ecological Footprint indicator.

A normalized composite formulation is represented as:

$$DEF = w_1E_n + w_2CO_{2n} + w_3W_n + w_4C_n \quad (4)$$

Where:

- DEF represents Digital Ecological Footprint score
- E_n represents normalized energy consumption
- CO_{2n} represents normalized carbon emissions
- W_n represents normalized e-waste/resource burdens
- C_n represents normalized economic cost
- w_1, w_2, w_3, w_4 represents assigned weights.

The application was implemented using HTML for the structure and user interface, PHP for server-side processing and application logic, MySQL for storing and retrieving user and environmental-impact data, and WAMP for integrating the Apache web server, PHP processing environment, and MySQL database during development. System testing involved functional testing of the major modules to determine whether data could be correctly entered, processed, stored, retrieved, and presented.

The application was subsequently evaluated using the Unified Theory of Acceptance and Use of Technology (UTAUT) as depicted in figure 3. UTAUT a model first proposed by Venkatesh et al. (2003) was selected to assess 30 users' acceptance and intention to use the developed Green ICT application based on performance expectancy, effort expectancy, social influence, and facilitating conditions. A structured questionnaire based on these constructs was administered among 30 respondents to selected prospective users of the application. Responses were measured using a Likert-scale instrument and analyzed using SPSS descriptive statistics, including frequency, percentage, mean, and standard deviation, while inferential analysis was employed to determine the relationships between UTAUT constructs and users' behavioural intention to use the application. The evaluation therefore assessed both the technical functionality of the developed system and its perceived usefulness, ease of use, social acceptance, and facilitating conditions, providing evidence of its suitability as a tool for supporting sustainable digital transformation and reduction of Nigeria's digital ecological footprint.

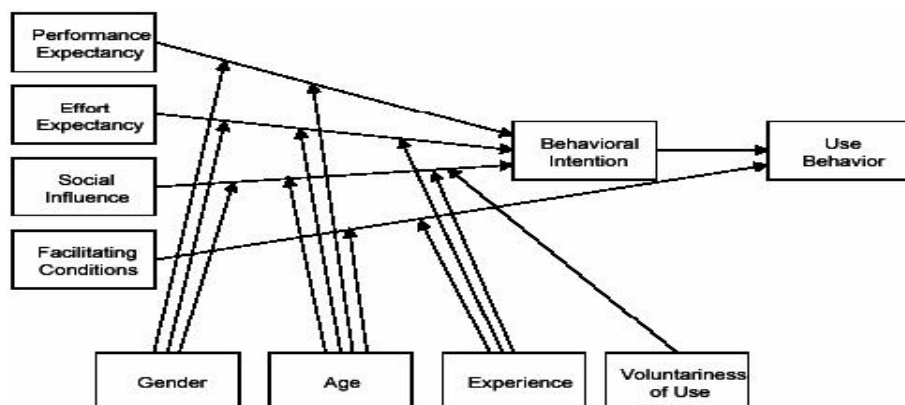


Figure 3: Unified Theory of Acceptance and Use of Technology (UTAUT) Venkatesh et al. (2003)

The dataset of 30 users for evaluating the Green ICT web application using UTAUT includes demographic variables and Likert-scale responses 1–5 Likert scale, where 1 = Strongly Disagree and 5 = Strongly Agree for: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), and Behavioural Intention (BI) as illustrated in table 1 as construct scores

Table 1: Descriptive Characteristics of Respondents (N = 30) Snow Ngozi Monye

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	16	53.3
	Female	14	46.7
Age	18–24 years	11	36.7
	25–34 years	10	33.3
	35–44 years	5	16.7
	45 years and above	4	13.3
User Category	Student	9	30.0
	Academic Staff	7	23.3
	ICT Staff	5	16.7
	Administrative Staff	6	20.0
	Environmental Officer	3	10.0
Total		30	100.0

RESULTS

Development

The Web-Based Green ICT Management Application is designed to support monitoring and reduction of the digital ecological footprint associated with ICT usage. The interface provides a simple and user-friendly entry point through which users can access the major functions of the system. The top navigation bar contains the Green ICT application name and Login and Register options, allowing existing users to authenticate and new users to create accounts. The central section introduces the application as a tool for monitoring and reducing Nigeria's digital ecological footprint through data-driven Green ICT management. The Get Started button provides direct access to the application. Three major functional areas are highlighted. Energy Monitoring enables users to assess electricity consumption associated with ICT equipment. Carbon Assessment supports the estimation of carbon emissions resulting from ICT-related energy use. Green Recommendations provides recommendations aimed at reducing the environmental impact of ICT operations.

Web-Based Green ICT Management Application

Monitoring and reducing Nigeria's digital ecological footprint through data-driven Green ICT management.

Get Started

Energy Monitoring

Estimate ICT-related electricity consumption.

Carbon Assessment

Estimate carbon emissions associated with ICT use.

Green Recommendations

Generate recommendations for reducing ecological impacts.

Figure 4: Web-Based Green ICT Management Application Snow Ngozi Monye

Evaluation

The results indicate generally positive perceptions of the proposed Green ICT application based on the mean scores presented in table 2, with all UTAUT constructs recording mean scores above 3.80. Behavioural Intention (M = 4.11) and Facilitating Conditions (M = 4.09) recorded the highest mean scores, indicating strong user willingness to use the application and positive perceptions regarding the availability of conditions needed for its use. Effort Expectancy (M = 4.08) also received a high rating, suggesting that respondents considered the application relatively easy to use, while Social Influence (M = 3.91) and Performance Expectancy (M = 3.83) indicate that respondents generally perceived social support and useful performance benefits from the application. The findings suggest a high level of acceptance and potential adoption of the proposed Green ICT application among the respondents.

Table 2: Descriptive Statistics of UTAUT Constructs Snow Ngozi Monye

UTAUT Construct	No. of Items	Mean (M)	Standard Deviation	Interpretation
Performance Expectancy (PE)	4	3.83	0.55	High
Effort Expectancy (EE)	4	4.08	0.52	High
Social Influence (SI)	4	3.91	0.42	High
Facilitating Conditions (FC)	4	4.09	0.42	High
Behavioural Intention (BI)	3	4.11	0.56	High

Figure 4 presents the mean scores and standard deviations of the UTAUT constructs used to evaluate the Green ICT application. All constructs recorded relatively high mean values, ranging from 3.83 to 4.11, indicating generally positive user perceptions. Behavioural Intention (BI) had the highest mean score (4.11), followed by Facilitating Conditions (FC) (4.09) and Effort Expectancy (EE) (4.08). Social Influence (SI) recorded a mean of 3.91, while Performance Expectancy (PE) had the lowest mean of 3.83. Overall, the

results indicate that respondents considered the application useful, relatively easy to use, adequately supported, and showed a strong intention to use it. The error bars represent the standard deviations, showing the variation in respondents' ratings across the constructs.

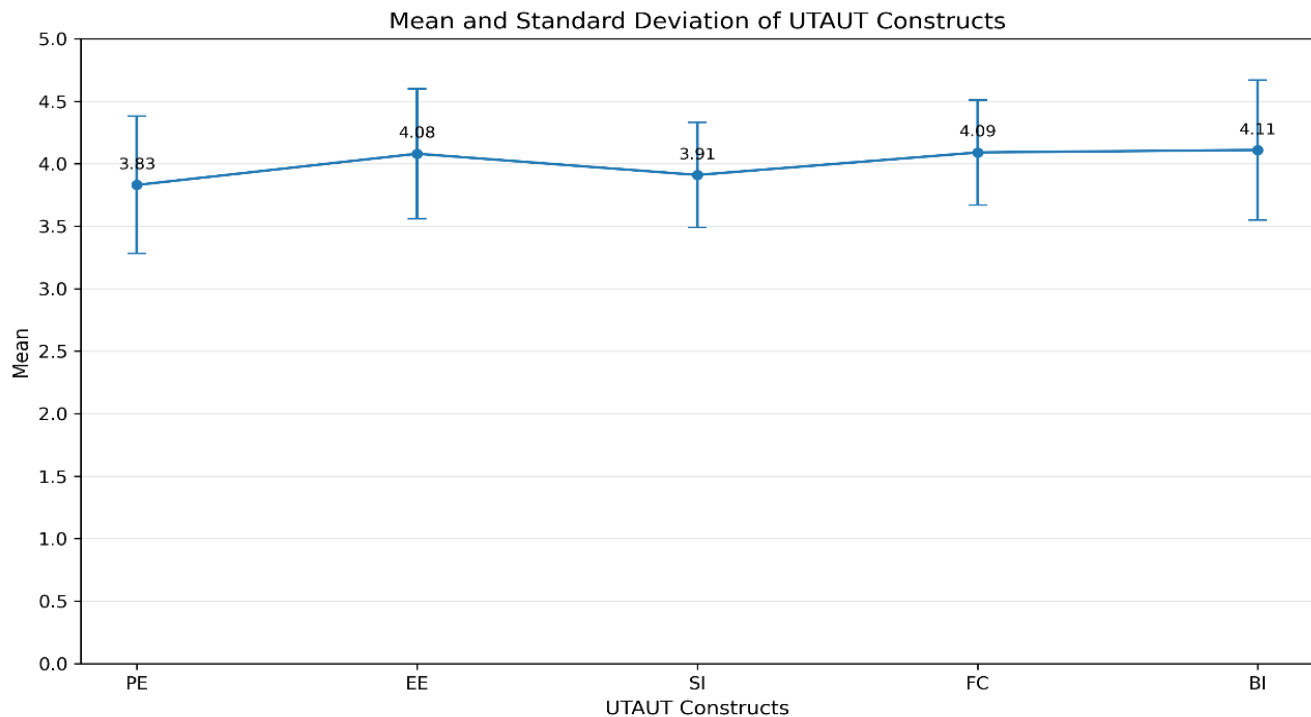


Figure 4: Mean and Standard Deviation curve Snow Ngozi Monye

The results showed positive relationships among all five UTAUT constructs as shown in table 3. The strongest relationship is between Effort Expectancy and Facilitating Conditions ($r = .749$, $p < .001$), while the weakest is between Performance Expectancy and Behavioural Intention ($r = .375$, $p = .041$). All relationships are statistically significant at the $p < 0.05$ level as depicted in figure 5.

Table 3: Pearson Correlation Matrix of UTAUT Constructs

Construct	PE	EE	SI	FC	BI
PE	1.000	.535	.721	.668	.375
EE	.535	1.000	.583	.749	.671
SI	.721	.583	1.000	.686	.615
FC	.668	.749	.686	1.000	.646
BI	.375	.671	.615	.646	1.000

The heatmap in figure 5 illustrates the Pearson correlation relationships among the UTAUT constructs. The results show generally strong positive associations among the constructs, with correlation coefficients ranging from 0.62 to 0.75. The strongest relationship is between Effort Expectancy (EE) and Facilitating Conditions (FC), $r = 0.75$, followed by Performance Expectancy (PE) and Effort Expectancy (EE), $r = 0.72$. Behavioural Intention (BI) also shows strong positive relationships with the other constructs, particularly FC ($r = 0.73$). Overall, the warm colours indicate strong positive correlations, suggesting that favourable perceptions of usefulness, ease of use, social influence and facilitating conditions are associated with stronger behavioural intention to use the Green ICT application.

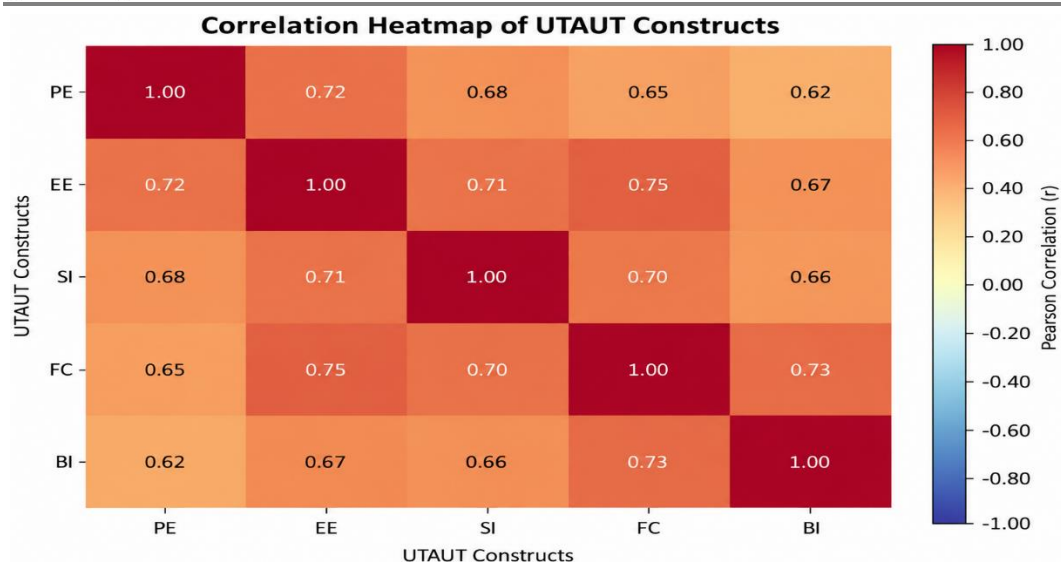


Figure 5: Correlation Heatmap of UTAUT Constructs Snow Ngozi Monye

The 3D diagram in figure 5 presents the correlation structure among the UTAUT constructs: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), and Behavioural Intention (BI). The vertical axis represents the Pearson correlation coefficient (r), while the colour gradient indicates the strength of the relationships. The warmer colours represent stronger positive correlations, whereas cooler colours indicate lower correlation values. The elevated areas of the surface correspond to stronger relationships, particularly among EE, FC, PE, SI and BI.

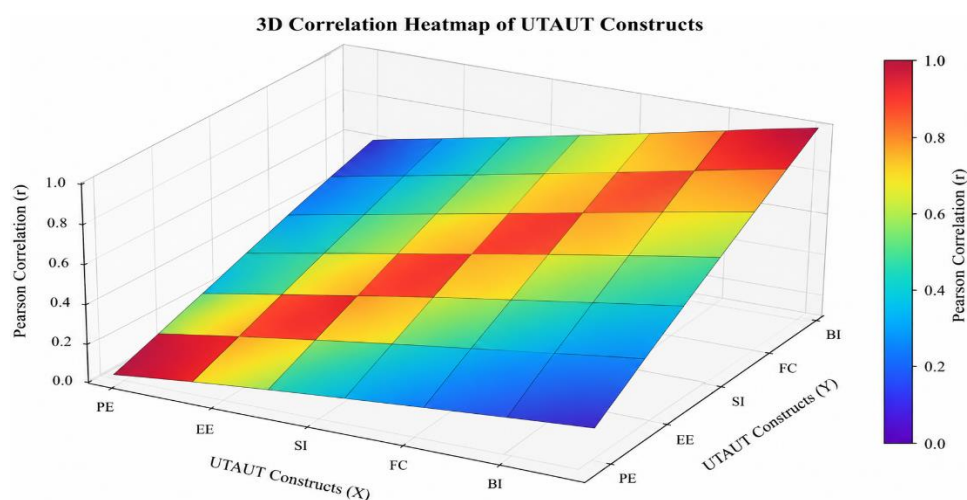


Figure 5: 3D UTAUT Constructs Snow Ngozi Monye

DISCUSSION

1. The study developed a web-based Green ICT Management Application for monitoring and reducing the digital ecological footprint associated with ICT use in Nigeria. The application integrates ICT data collection, energy assessment, carbon-emission estimation, e-waste/resource assessment, Digital Ecological Footprint (DEF) calculation, and Green ICT recommendations. The use of the Waterfall model provided a structured approach to requirements analysis, system design, implementation, testing and maintenance. This approach is consistent with Priyana et al. (2025), who also adopted a structured development approach in developing a Green IT-based website. However, while Priyana et al. (2025) focused mainly on providing cocoa cultivation information through a Green IT website, the present study extends the concept by incorporating environmental calculations and decision-support functions.

Similarly, Borissova et al. (2025) demonstrated the usefulness of web-based applications in supporting green-transition decision-making. The present study aligns with this work by demonstrating how a web-based platform can be used not only for information delivery but also for monitoring and managing environmental impacts associated with ICT activities.

2. The integration of energy consumption, carbon emissions and e-waste assessment into the application is consistent with the environmental challenges identified in previous Nigerian studies. Olanrewaju et al. (2025) identified dependence on fossil-fuel-based electricity, weak emission reporting, inefficient e-waste management and limited renewable-energy adoption as major sustainability challenges in Nigeria's ICT sector. The present application addresses part of these challenges by providing a mechanism for estimating ICT electricity consumption and converting energy use into associated carbon emissions. The inclusion of e-waste assessment further broadens the analysis beyond energy and carbon to consider the material consequences of ICT equipment use and replacement. The findings also relate to Tukur, Abdullahi and Abdulmalik (2026), who reported that only 48.4% of their 500 respondents were aware of digital carbon footprints. The present application can contribute to addressing this awareness gap by presenting environmental impacts as measurable indicators rather than abstract sustainability concepts. In addition, the proposed DEF model combines normalized energy consumption, carbon emissions, e-waste/resource burden and economic cost into one composite indicator. This integrated approach provides a broader assessment of ICT environmental impact than studies that focus on a single dimension of digital sustainability.
3. The evaluation results demonstrate generally high acceptance of the developed application, with all UTAUT constructs recording mean scores above 3.80. Behavioural Intention recorded the highest mean ($M = 4.11$), followed by Facilitating Conditions ($M = 4.09$) and Effort Expectancy ($M = 4.08$). These results indicate that respondents were generally willing to use the application and considered it relatively easy to operate. The findings are consistent with Priyana et al. (2025), who reported acceptance levels above 85% for their Green IT website, particularly in terms of usefulness, appearance, functionality and efficiency. Although Priyana et al. used User Acceptance Testing while the present study employed UTAUT, both studies indicate that usability and perceived usefulness are important to the successful adoption of Green ICT applications. The findings also have similarities with Ramos et al. (2026), who found that perceived usefulness and website quality positively influenced continuance intention. In the present study, Performance Expectancy recorded a high mean of 3.83, suggesting that respondents generally recognized the usefulness of the application. However, its relationship with Behavioural Intention was the weakest significant correlation ($r = .375$, $p = .041$). This suggests that although usefulness is important, users' willingness to adopt the application may also depend on ease of use, social influence and the availability of supporting conditions.
4. The Pearson correlation results revealed significant positive relationships among all the UTAUT constructs. The strongest relationship occurred between Effort Expectancy and Facilitating Conditions ($r = .749$, $p < .001$), while Behavioural Intention was positively related to Effort Expectancy ($r = .671$, $p < .001$), Social Influence ($r = .615$, $p < .001$) and Facilitating Conditions ($r = .646$, $p < .001$). These results suggest that users' willingness to adopt the Green ICT application is associated not only with its perceived usefulness but also with its ease of use, social support and availability of technical or organizational conditions. This finding supports the broader arguments of Odiche and Akeem (2024) that successful digital transformation requires sustainability-oriented strategies and appropriate supporting frameworks. It also complements Olanrewaju et al. (2025), who emphasized the need for stronger institutional and policy mechanisms for Green ICT adoption in Nigeria. Therefore, the successful implementation of the developed application may require more than technical deployment; organizations may also need user training, management support, environmental policies and appropriate ICT infrastructure.

CONCLUSION

This study developed and evaluated a Web-Based Green ICT Management Application for monitoring and reducing Nigeria's digital ecological footprint. The application integrates ICT data collection, energy-consumption assessment, carbon-emission estimation, e-waste and resource assessment, Digital Ecological

Footprint calculation, and Green ICT recommendations within a unified platform. The evaluation demonstrated generally positive user acceptance and confirmed the feasibility of using a web-based platform to support the monitoring and management of ICT-related environmental impacts. The study therefore concludes that the proposed application provides a practical foundation for promoting data-driven Green ICT practices and supporting sustainable digital transformation in Nigeria. It is recommended that organizations, higher institutions and ICT-intensive establishments in Nigeria adopt web-based Green ICT monitoring systems to regularly assess ICT energy consumption, carbon emissions, e-waste and associated costs, thereby enabling informed decisions on energy efficiency, responsible ICT equipment management and reduction of digital environmental impacts. The major limitation of the study is that the environmental assessment depends partly on user-provided ICT equipment and utilization data, which may introduce measurement or reporting inaccuracies and limit the precision of the calculated ecological-footprint indicators. Future research should focus on integrating IoT-enabled smart meters and sensors into the application to enable automated and real-time collection of ICT energy-consumption data, while conducting longitudinal studies to determine the actual effect of the system on energy consumption, carbon emissions, e-waste generation and overall digital ecological footprint.

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