

## Digital Transformation and Resource Efficiency in Africa: Evidence from Nigeria's ICT Expansion and Carbon Emissions

Oluwasegun A. Adekoya<sup>1,2</sup>, Oluwasogo S. Adediran<sup>1</sup>, David O. Olukanni<sup>1</sup>, Rehema J.  
Monko<sup>2</sup>

<sup>1</sup>Covenant University, Ota, Nigeria, <sup>2</sup>Ardhi University, Dar Es Salaam, Tanzania.  
oluwasegun.adekoyapgs@stu.cu.edu.ng

DOI: <https://doi.org/10.5281/zenodo.18050009>

### Abstract

This study investigated the role digital transformation plays in shaping environmental outcomes in Nigeria, with particular focus on carbon dioxide (CO<sub>2</sub>) emissions. Using annual time series data sourced from World Bank Development Indicators from year 2000-2024, the result after estimating through Autoregressive Distributed Lag, revealed that fixed broadband penetration significantly reduces CO<sub>2</sub> emissions in the long run, suggesting that advanced digital infrastructure enhances energy efficiency and supports resource-efficient production and service delivery. Internet usage, although negatively related to emissions, remains statistically insignificant, reflecting structural constraints in Nigeria's fossil-fuel-dominated energy system. The study recommends clean energy investments and effective institutional frameworks.

**Keywords:** Carbon Dioxide Emissions, Clean Energy, Digital Transformation, Resource-efficient.

### 1. INTRODUCTION

Africa's resource economy is currently undergoing a profound transformation as digital technologies increasingly shape the productive system, energy use and environmental outcomes. Information and Communication Technologies (ICT) has been rapidly diffused into the energy sector by introducing new pathways for improving productivity while reducing the material and energy intensity of economic activities. Within the lens of the global outlook, digitalization has been linked to enhanced energy efficiency, reduced cost of transaction, and virtual alternatives substituting for physical processes, all of which carry implications for carbon emissions and resource use (González-Zamar *et al.*, 2020). In developing regions like Africa where industrialization remains resource-intensive and the energy system is dominated by fossil fuels, the question of whether digital expansion contributes to environmental improvement remains central to policy and research debates.

Nigeria provides an important context for examining this relationship. Given Africa's largest economy and digital market, the country has witnessed significant growth in ICT infrastructure over the years. Broadband penetration increased from 10% in 2015 to over 40% by 2023, while internet usage has rapidly expanded across households and firms (International Telecommunication Union, 2023). Alongside, Nigeria's energy sector currently faces persistent supply deficits, high dependency on fossil fuels, and rising carbon emissions due to the increasing population and increased economic activities. It is therefore imperative and vital to understand

whether digitalization eases or exacerbates environmental pressure for national planning and for Africa's broader green transition agenda.

There has been a mix in the empirical findings on ICT-environment nexus, which suggests ICT can reduce emission by enabling energy-saving technologies, smart production systems and resource-efficient logistics. Conversely, studies focusing on developing countries highlight that digitalization can initially increase electricity demand especially where grids remain fossil-fuel dependent which leads to higher emissions in the absence of complementary clean-energy investments (Avom *et al.*, 2020; Nathaniel *et al.*, 2021). These contrasting outcomes indicate that ICT's environmental impact is context-specific and heavily mediated by energy structure, institutional quality, and the composition of imported digital technologies.

Despite the growing array of literature, substantial evidence for Africa particularly Nigeria remains limited and under-studied. Quite a number of existing works focuses either on the environmental effect of economic growth and energy consumption or the role technology plays in productivity, which practically leaves a gap in understanding how digital infrastructure directly shapes carbon outcomes within a resource-dependent economy. In this light of this identified gap, this study contributes to filling this gap by empirically examining the relationship between digital transformation through ICT expansion and carbon emission in Nigeria. This is with a focus on fixed broadband subscriptions and individuals using the internet. By integrating both short-run and long-run dynamics, the study assesses whether Nigeria's digital transformation enhances resource efficiency or reinforces traditional carbon-intensive growth patterns. The findings hold implications not only for Nigeria's climate and digital policy frameworks but also for Africa's broader pursuit of a resource-efficient, technology-enabled development trajectory.

## 2. LITERATURE REVIEW

Empirical studies on the relationship between digitalisation and environmental outcomes have over the years produced mixed but increasingly nuanced results. On a global scale, (IEA, 2021; IEA, 2023), noted that digital systems particularly data centres and transmission networks account for a measurable share of energy demand and this by implication, increases electricity consumption unless offset by efficiency and clean power strategies. Econometric studies while complementing the IEA's system-level perspective, have shown divergent country level effects. Zhang *et al.*, (2022) discovered that in certain Asian economies, internet and ICT adoption are associated with an improvement in environmental quality, particularly where governance and human capital are supportive. This stresses the efficiency and substitution channel where digital services have taken the position of carbon intensive activities such as travel and paper-based services.

Within the developing regions, Li and Zhang (2023,) and some other researchers have shown that an expansion in ICT could potentially increase the use of energy and further add more pressure to the environment. This is factored by rising data traffic, device proliferation and network expansion raise electricity demand; when grids are fossil-fuel dominated, the net effect could be higher emissions. Ugwu *et al.*, (2020) highlights that although renewable potential is substantial, the regulatory, technical and financial barriers have limited uptake which implies that, increased electricity demand from digitalisation will often be accommodated by existing fossil-based generation.

Recent evidence indicates that mobile cellular subscriptions in African countries are associated with higher CO<sub>2</sub> emissions in the long run, highlighting the energy intensity of ICT infrastructure

in contexts dominated by fossil fuel electricity. Ugwu, Odo, Oluka, and Salami (2022) systematically review renewable energy development in Nigeria and find that financial, technical, and regulatory barriers limit the adoption of green technologies, thereby constraining the environmental benefits of digital infrastructure. Onifade, Erdogan, and Alola (2023) show that globalization and alternative energy adoption interact complexly with resource-dependent economies in Africa, often delaying decarbonisation despite growing ICT penetration. Micro-level studies in Nigeria further illustrate that ICT-enabled renewable solutions, such as pay-as-you-go solar systems, can reduce fossil energy reliance at the household and community level, yet face scaling challenges due to maintenance costs, tariff structures, and institutional inefficiencies (Olayungbo, Faiyetole, & Olayungbo, 2024). These findings emphasise that the Nigerian context presents both opportunities and constraints, where ICT expansion increases electricity demand but can support renewable adoption if properly integrated with energy and regulatory frameworks.

### 3. METHODOLOGY

The model explores both the long-run and short-run relationships between Digital Transformation and Resource Efficiency in Africa from 2000 to 2024. Data were obtained from the World Development Indicators. Carbon dioxide (CO<sub>2</sub>) emissions, represented by CO<sub>2</sub> as the dependent variable, is specified as a function of the independent variables: MTP, MMM, ICT, PCW, and GDPPC.

The equation expressed in log-linear form as:

$$CO_{2t} = \beta_0 + \beta_1 FBB_t + \beta_2 IUT_t + \beta_3 GPPPC_t + \beta_4 ATE_t + \varepsilon_t \quad (3.1)$$

Where: LREE Carbon dioxide emission; FBB represents Fixed broadband subscription; IUT represents Individuals using the internet; GDPPC represents Gross domestic product per capita; ATE represents Access to electricity; and  $\varepsilon_t$  represents error term.

### 4. ANALYSIS

**Table 1: Short-run and Long-run ARDL Model Estimation**

SHORT-RUN RESULT				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.34276	0.201586	-1.70034	0.1129
CO <sub>2</sub>	-0.39075	0.159943	-2.44306	0.0296
FIXEDBROADBAND	-5.06E-07	2.78E-07	-1.8196	0.0919
INDIVIDUALS USING THE INTERNET	-0.00106	0.001271	-0.83479	0.4189
GDP PER CAPITA	2.58E-05	1.70E-05	1.518821	0.1527
ACCESS TO ELECTRICITY	0.012492	0.002863	4.362394	0.0008
CointEq(-1)*	-0.39075	0.047862	-8.16409	0.0002
LONG RUN RESULT				
FIXEDBROADBAND	-1.29E-06	4.83E-07	-2.67751	0.019
INDIVIDUALS USING THE INTERNET	-0.00272	0.003538	-0.76726	0.4566
GDP PER CAPITA	6.60E-05	6.13E-05	1.076828	0.3011
ACCESS TO ELECTRICITY	0.031969	0.016017	1.995858	0.0673

C	-0.8772	0.820224	-1.06946	0.3043
R-squared	0.903718	Mean dependent var	0.618263	
Adjusted R-squared	0.837061	S.D. dependent var	0.066998	
S.E. of regression	0.027044	Akaike info criterion	-4.08367	
Sum squared resid	0.009508	Schwarz criterion	-3.58998	
Log likelihood	56.96225	Hannan-Quinn criter.	-3.95951	
F-statistic	13.55778	Durbin-Watson stat	2.076383	
Prob(F-statistic)	0.00003			

*Source: Author's Computation, 2025*

## 5. DISCUSSION

The results of the ARDL long-run and short-run estimations reveal important dynamics between digital infrastructure and carbon emissions (CO<sub>2</sub>) in Nigeria. In the long run, fixed broadband subscriptions exhibit a significant negative effect on CO<sub>2</sub> emissions. This implies that as broadband penetration expands, Nigeria experiences a reduction in emissions, likely due to improved energy efficiency, increased adoption of digital processes, and reduced reliance on physically intensive economic activities. Improved digital access enables firms to digitalize operations, reduce travel, and substitute paper-based and manual processes with ICT solutions that have lower carbon intensity. This finding aligns with emerging evidence that modernization and technological improvements can support cleaner development pathways, as seen in Nigeria's transition case documented by Yekini *et al.* (2024), who highlighted the importance of digital-energy efficiency in achieving cleaner production patterns. As a result, Nigeria should accelerate nationwide broadband deployment particularly in industrial hubs and public institutions while pairing broadband expansion with energy-efficient ICT standards. Integrating renewable-powered telecom towers and encouraging digital workspaces can amplify the emission-reducing effects already observed.

In contrast, the long-run effect of internet usage is negative but statistically insignificant. Although internet penetration is rising, its influence on emissions remains muted because Nigeria's electricity supply is still heavily fossil-fuel dependent. Digital activities increase electricity demand, but without a strong renewable foundation, the environmental benefits do not manifest. This aligns with observations by Ugwuwa *et al.* (2022), who emphasized that Nigeria must expand renewable capacity before digital growth can translate into environmental gains. Similar patterns appear in Arowolo and Douglas (2022), which showed that Nigeria's dependence on fossil-fuel generation constrains the potential environmental benefits of technological adoption. There should be a strengthening of the national grid with renewable energy investments especially in solar mini-

grids so that growing digital activity is powered by clean energy. This dual action allows internet-driven development to align with climate goals.

ICT goods imports also show insignificant long-run effects on emissions. While imported ICT equipment could support cleaner technologies, the environmental benefits may be delayed due to deployment constraints, low technical absorption, and infrastructure deficits. This trend has been identified by Onifade *et al.* (2023), who noted that Nigeria's technological adoption often lags due to weak institutional systems and inadequate implementation frameworks.

However, in the short run, lagged ICT goods imports exhibit a positive and significant effect, implying that imported technologies begin contributing to lower emissions once implemented or integrated into production and monitoring systems. This resonates with the evidence from Olayungbo *et al.* (2024), who stressed that decentralized energy technologies including ICT-enabled systems play a meaningful role in reshaping Nigeria's sustainable energy landscape. As a policy action point, provision of targeted incentives for importing renewable-enabling ICT goods such as smart meters, efficient servers, and solar-compatible devices while establishing a national framework for ICT deployment and maintenance to speed up technology diffusion.

Access to electricity demonstrates a positive and significant short-run effect, indicating that as more Nigerians gain grid access, emissions temporarily rise due to the fossil-dominant nature of the grid. This outcome is supported by Ugwua *et al.* (2022), who documented that Nigeria's electricity expansion currently depends heavily on gas and diesel. However, the long-run coefficient, though positive, approaches significance, suggesting that structural improvements if aligned with renewable expansion can reduce environmental trade-offs over time. Given this, there should be an integration of renewable energy into grid expansion programmes. Each new community connected to the grid should benefit from hybrid or renewable-based distribution, reducing the emission burden of electrification.

GDP per capita shows no significant long-run or short-run effect, suggesting that economic growth in Nigeria has not yet transitioned toward a cleaner structure. This reflects the situation described by Onifade *et al.* (2023), who noted that economic growth in Nigeria continues to correlate with higher fossil fuel usage due to limited green industrialization. The government should promote green industrial policy especially renewable-powered manufacturing clusters and digital-innovation corridors so that future economic expansion does not intensify carbon emissions.

Overall, the results show that digital infrastructure can reduce emissions when supported by renewable energy investments and effective institutions, but alone, digitalization does not automatically lead to environmental sustainability.

## 6. CONCLUSION AND IMPLICATION

This study provides empirical evidence on the environmental implications of digital transformation in Nigeria by examining the relationship between the expansion of ICT and carbon dioxide emission over the period 2000-2024. The findings revealed with the intentional availability, access and use of these ICT tools, carbon dioxide can be reduced in Nigeria, although Nigeria dependency on fossil-fuel limits the extent by which digital activities translate into emission reductions. From a policy standpoint, these findings indicate that digitalisation should not be pursued as a stand-

alone strategy for environmental sustainability. Instead, its effectiveness depends on energy-efficient ICT standards, integration of renewable energy deployment, and the capacity of the institution. When such is not aligned, digital expansion risks reinforcing existing carbon-intensive development patterns rather than transforming them.

## 7. LIMITATIONS AND FURTHER STUDIES

Further studies could also expand the geographical scope to West Africa which could include other regional blocs in Sub-Saharan Africa, allowing for comparative analysis.

**ACKNOWLEDGEMENT:** The authors acknowledge Africa Sustainable Infrastructure Mobility (ASIM) under the European Union, Covenant University and Ardhi University.

**Authors Declaration:** The authors declare that this study is original, plagiarism free and adheres to ethical publication standard.

**Authors Contribution:** Introduction David Olukanni and Literature Review Oluwasogo Adediran, Methodology Rehema Monko, Analysis, Discussion of Result and Conclusion and Implication, Oluwasegun Adekoya.

**Funding:** The authors acknowledge Africa Sustainable Infrastructure Mobility (ASIM) under the European Union for the funding

**Data Availability Statement:** The data utilized for this study will be made available upon reasonable request.

**Conflicts of Interest:** The authors declare no conflict of interest.

## REFERENCES

- Arowolo, A. O., & Douglas, C. E. (2022). *Electricity generation and renewable energy policy in Nigeria: Assessing innovation drivers for cleaner energy transitions*. American Journal of Environment and Climate, 1(2), 42–52. <https://journals.e-palli.com/home/index.php/ajec/article/view/258>
- Avom, D., Nkengfack, H., Fotio, H. K., & Totouom, A. (2020). *ICT and environmental quality in Sub-Saharan Africa: Effects and transmission channels*. Technological Forecasting and Social Change, 155, 120028. <https://doi.org/10.1016/j.techfore.2020.120028>
- González-Zamar, M.-D., Abad-Segura, E., López-Meneses, E., & Gómez-Galán, J. (2020). Managing ICT for sustainable education: Research analysis in the context of higher education. *Sustainability*, 12(19), 8254. <https://doi.org/10.3390/su12198254>
- International Telecommunication Union. (2023). *Measuring digital development: Facts and figures 2023*. <https://www.itu.int/itu-d/reports/statistics/facts-figures-2023>

- Li, Y., & Zhang, Y. (2023). *What is the role of green ICT innovation in lowering carbon emissions in China? A provincial-level analysis*. *Energy Economics*, 127 (Part A), Article 107112. <https://doi.org/10.1016/j.eneco.2023.107112>
- Nathaniel, S. P., & Adeleye, N. (2021). *Environmental preservation amidst carbon emissions, energy consumption, and urbanization in selected African countries: Implication for sustainability*. *Journal of Cleaner Production*, 285, 125409. <https://doi.org/10.1016/j.jclepro.2020.125409>
- Olayungbo, D. O., Faiyetole, A. A., & Olayungbo, A. A. (2024). *Investigating the role of subsistence renewables in alleviating power poverty within Nigeria's energy-mix strategy*. *Sustainable Energy Research*, 11, Article 11. <https://doi.org/10.1186/s40807-024-00105-3>
- Onifade, S. T., Erdoğan, S., & Alola, A. A. (2023). *The role of alternative energy and globalization in decarbonization prospects of the oil-producing African economies*. *Environmental Science and Pollution Research*, 30(20), 58128–58141.
- Ugwu, J., Odo, K. C., Oluka, L. O., & Salami, K. O. (2022). *A systematic review on the renewable energy development, policies and challenges in Nigeria with an international perspective and public opinions*. *International Journal of Renewable Energy Development*, 11(1), 287–308.
- Yekini, I. A., Ogunbiyi, T., & Adejuwon, O. (2024). *Clean and sustainable energy revolution in Nigeria: Challenges, potentials and policy recommendations*. *African Journal of Environmental Sciences & Renewable Energy*, 2(1), 77–92. <https://afropolitanjournals.com/index.php/ajesre/article/view/271>
- Zhang, C., Khan, I., Dagar, V., Saeed, A., & Zafar, M. W. (2022). *Environmental impact of information and communication technology: Unveiling the role of education in developing countries*. *Technological Forecasting and Social Change*, 178, 121570. <https://doi.org/10.1016/j.techfore.2022.121570>