Environmental Degradation, Digital Economic Transformation, and Inclusive Economic Growth in Nigeria

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Abstract
Nigeria is experiencing rapid environmental degradation and a rapid digital economic transition at an unequal pace, where the benefits of growth are accrued by a small number of people. The research finds out about the effects of environmental degradation on inclusive growth in Nigeria between 1990-2024 and the digital economic transformation. An ex post facto quantitative design using a data of yearly time series data for Nigeria within the period 1990 to 2024 (35 observations) was adopted. Environmental degradation is measured through CO_2 emissions per capita, digital transformation and inclusive growth are composite indices based on PCA of the ICT indicators and socioeconomic indicators, respectively. The following tests are performed: Autoregressive Distributed Lag bounds testing, error-correction modelling and Fully Modified OLS robustness checks, as well as Granger causality tests. The result reveals a stable relationship: Digital transformation has a significant positive effect on inclusive growth, whereas environmental degradation has a negative impact, and vice versa, a portion of the degradation's welfare losses is offset by digitalisation. It calls for execution of green digital infrastructure into a national development plan, scaled-up rural broadband and digital skills initiatives, robust environmental laws and regulations and renewable energy sourcing of digital services.

Keywords: *Environmental Degradation; Digital Economy; Inclusive Growth; ARDL; Nigeria*

1.0 Introduction

Globally, economic growth has long been associated with increasing resource use and ecological pressure, yet the digital revolution has introduced a new and contested dimension to this relationship (Ekonomou and Halkos, 2023). Digital technologies have the possibility of enhancing productivity, expand market access and reduce transaction costs but require significant energy infrastructure and produce electronic waste (Ma and Zhu, 2022; Usman et al., 2021). Inclusive economic growth, that is sustainable across time, across sectors, and across society, thus relies on the management of the interplay between ecological limits and technological change (Myovella et al., 2020). Evidence of environmental stress is compelling globally. The impact of human activities has resulted in a temperature rise, approximately 1.1 degrees Celsius before industrial era, with significant consequences for food systems, water security, and livelihoods (Intergovernmental Panel on Climate Change, 2023). Research on the advanced and emerging economies indicates

that digitalisation contributes to efficiency gains, dematerialisation, and the smarter management of resources, thereby boosting output and emission intensity under the right circumstances (Nguyen et al., 2020). However, Li and Wang (2022) opined that the growth of the virtual economy has the capacity to reduce carbon emissions at city level, as found in China, where this relationship depends on the composition of industrial activities and energy sources. The global lesson is that digitalisation does not necessarily have a green or inclusive face, as their outcomes rely on institutions, energy sources and skills.

Africa emits the least, but is the most affected by the climate change, in terms of drought, flooding, desertification, and coastal erosion (Dube et al., 2016). The continent ranks as one of the continents with the best growth in digital markets, fuelled by mobile telephony, mobile money and a growing number of people access the internet (Omol et al., 2024). The proof from Sub-Saharan Africa reveals that information and communication technology (ICT) can be used to promote the environmental quality through the specific transmission channels of energy efficiency, financial development, and institutional quality (Avom et al., 2020). Comparative work also indicated that in Sub-Saharan Africa digitalisation has an impact on growth, but that this impact is smaller than in Organisation for Economic Co-operation and Development economies given that there are skill and infrastructure deficits in the countries of Sub Saharan Africa (Myovella et al., 2020). The continent is thus challenged to use digitalisation as a tool to drive sustainable growth across the board without getting stuck in ecologically unsustainable growth trajectories (Saba et al., 2026).

Nigeria is the biggest economy in Africa, and the most populous country in Africa, it is a prime example of this problem. The effects of environmental degradation are evident in the gas flaring, oil pollution in the Niger Delta, high rate of deforestation, desertification in the north, gully erosion in the south-east and recurrent flooding affecting millions of households (Onya, 2016). Yusuf (2023) noted that economic growth, energy consumption and urbanisation are important contributors to carbon emissions in Nigeria. At the same time, the country has seen the increase of mobile penetration, and fintech activity at an incredible pace (Asaju, K., and Ashepo, 2025). Nonetheless, poverty rates are high and unemployment is prevalent, inequality persists, and growth has not been accompanied by widespread prosperity (Adenike, 2021). The interplay between ecological pressure and digital reform in the context of inclusive growth is thus a critical policy issue in Nigeria's future development policy (Ololube and Nweke, 2025).

Nigeria has some persistent challenges to its growth. Environmental degradation is increasing and has a genuine economic cost, in terms of the productivity of the land, health impacts, displacement and damaged infrastructure (Nguyen et al., 2023). The digital economy is rapidly growing but access and affordability of digital services are unevenly distributed among regions, gender and income groups, and digital gains can further amplify disparities rather than narrow them (Musa et al., 2025). Scholars focus on either digital economy and environment or digital economy and growth and is mostly confined to Asia and advanced economies (Usman et al., 2021; Chen et al., 2022). There is a lack of studies that examine environmental degradation, digital transformation, and inclusive growth together and in relation to Nigeria, and even fewer studies that put to test whether digitalisation can serve as a moderating effect on the welfare cost of environmental degradation. This void presents a challenge for policymakers because there is no evidence on whether digital transformation can be a catalyst for inclusive and sustainable growth in Nigeria.

This study aims at finding out the impacts of environmental degradation and digital economic transformation on inclusive economic growth in Nigeria.

2.0 Literature Review

2.1 Theoretical Review

2.1.1 Environmental Kuznets Curve (EKC)

The EKC suggests that there is a curve that separates profit from environmental degradation (Kiliç and Balan, 2018). There is enhancement of pollution at the beginning of growth and decreases after a certain threshold income is attained because as societies improve, they demand cleaner surroundings and employ cleaner technologies (Ali et al., 2023). There has been no evidence of clear consensus regarding the empirical evidence, and recent studies highlight the importance of technology and energy structure in determining the turning point. A hydrocarbon-reliant economy like Nigeria requires a baseline to understand the reasons for a short-term deterioration of the ecological indicators as growth takes place (Ulucak and Khan, 2020).

2.1.2 Endogenous Growth Theory

In endogenous growth models, technological progress, and knowledge spillovers are viewed as endogenous sources of long-run growth (Ehrlich and Pei, 2020). Digital technologies act as a general-purpose technology that can be applied to all industries to boost productivity, reduce information costs and create new business models (Sultan, 2026). This theory forms the foundation for the belief that digital reform has the capacity to boost growth and increase inclusiveness in its broader application (Appiah-Otoo and Song, 2021).

2.1.3 Ecological Modernisation Theory

This point of view contends that technological innovation and institutional transformation can separate economic activity from environmental damage (Mol et al., 2020). The decoupling potential is shown by digital tools like remote sensing and digital monitoring of emissions (Ma and Zhu, 2022).

2.2 Conceptual Review

Environmental Degradation: is defined as loss of the environment through resources depletion (air, water, soil etc.), destruction of ecosystems and habitat loss and pollution. Some of the common proxies are carbon dioxide emissions, ecological footprint, deforestation, and land degradation (Ulucak and Khan, 2020).

Digital Economic Transformation: refers to the transformation of economic activity by leveraging digital technology, such as Internet and mobile access, electronic payments, e-commerce, cloud services, and data-driven production (Myovella et al., 2020). It is usually expressed in terms of ICT penetration indicators or composite digital economy indices (Li and Wang, 2022).

Inclusive Economic Growth: is a growth that has to increase the average income, increase employment and economic opportunities for all, including the poor and marginalised, and reduce inequality. No single measure captures it, so there are more composite measures that combine income growth, employment, poverty and inequality (Avom et al, 2020).

Linkages among the concepts. Inclusiveness can be jeopardized by environmental degradation since the poor rely heavily on natural resources and have the least adaptive capacity. Digital transformation can help drive inclusion by creating more market, finance and information access, yet can deepen exclusion if there is a digital divide. Depending on energy sources and

consumption, digital technologies can also alleviate or exacerbate environmental stress (Avom et al, 2020).

2.3 Empirical Review

Usman *et al.* (2021) reported the impacts of ICT on carbon emissions are asymmetric in selected Asian economies, meaning that shocks have a different effect on emissions. Based on the study by Ke et al. (2022), emissions can be affected in varying degrees by ICT and the globalisation of trade among different country panels. In their study, Nguyen *et al*. (2020) demonstrated that ICT and innovation add to the decarbonisation of the G-20 economies, as well as to growth. In the sub-national level, Chen *et al*. (2022) show that the introduction of artificial intelligence applications has a positive impact on carbon emission performance.

Avom *et al*. (2020) show that ICT increases environmental quality via a number of mechanisms, such as growth in finance and institutional quality in Sub Saharan Africa. Opoku and Aluko (2021) demonstrated that the environmental impacts of industrialisation vary by countries in Africa as well as by quantiles of emissions, and hence blanket policies may not work. In Nigeria specifically, Akpan and Akpan (2012) shows that both economic development and energy usage increase emissions for a long time, whereas forest area and value-added in agriculture have mitigating and conditioning effects. As far as growth is concerned, Myovella *et al*. (2020) concluded that in both the Sub-Saharan and the OECD economies, digitalisation has icreases growth, and this impact varies by income level, with mobile and internet effects having different impacts. Appiah-Otoo and Song (2021) demonstrate that benefits of ICT are higher in wealthy nations than in third world countries, highlighting the importance of complementary infrastructure and skills. Ma and Zhu (2022) assert that innovation in emerging economies will facilitate new economy development to promote high-quality green growth.

2.4 Research Gap

This study takes a different approach to the new economy, environment, growth relationship, as most studies focus on these two relationships separately. The literature tends to focus on growth of GDP, rather than the distributional and employment aspects that make something inclusive. For Nigeria, there is limited evidence and no study to the best of our knowledge scrutinises the moderating effect of virtual transformation in the relationship between degradation and inclusive growth within a time-series structure for small samples. The research will fill these gaps.

3.0 Study Methodology

3.1 Research Design

An ex post facto quantitative design using annual time series data for Nigeria covering the period 1990 to 2024 (35 observations), was used. Data were sourced from, National Bureau of Statistics and UNDP Human Development database. Table 1 shows the variables and how they are operationalized.

Table 1: Variables

Variable	Sign	Scale	Expected sign
Inclusive growth index	IGI	PCA composite of real GDP per capita growth, employment-to-population ratio, poverty headcount (inverse), and Gini coefficient (inverse)	Dependent
Environmental degradation	ED	CO_2 emissions per capita and annual forest loss (%), combined by PCA	Negative
Digital transformation	DIG	PCA composite of mobile subscriptions, internet users.	Positive
Interaction term	DIG×ED	Product of standardised DIG and ED	Positive
Foreign direct investment	FDI	Net inflows	Positive
Trade openness	TOP	(Exports + imports) / GDP	Positive
Energy use	EN	Energy use per capita (kg oil equivalent)	Ambiguous
Financial development	FD	Domestic credit to private sector	Positive

3.2 Model Specification

Guided by the endogenous growth and EKC frameworks, the functional relationship is specified as:

$$IGI = f(ED, DIG, DIG\times ED, FDI, TOP, EN, FD) \quad . \quad . \quad i$$

In log-linear econometric form:

$$\ln IGI(t) = \beta 0 + \beta 1\ \ln ED(t) + \beta 2\ \ln DIG(t) + \beta 3\ (\ln DIG \times \ln ED)(t) + \beta 4\ FDI(t) + \beta 5\ \ln TOP(t) + \beta 6\ \ln EN(t) + \beta 7\ \ln FD(t) + \varepsilon(t) \quad . \quad . \quad ii$$

where t denotes time and ε is the error term. A priori, $\beta 1 < 0$, $\beta 2 > 0$, $\beta 3 > 0$, and $\beta 4, \beta 5, \beta 7 > 0$.

3.3 Estimation Technique

The ARDL bounds-testing approach is adopted for three reasons, in line with the notion of Kripfganz and Schneide (2023). The unrestricted error-correction form is:

$$\Delta \ln IGI(t) = \alpha 0 + \Sigma\ \varphi i\ \Delta \ln IGI(t-i) + \Sigma\ \theta j\ \Delta X(t-j) + \lambda 1\ \ln IGI(t-1) + \lambda 2\ X(t-1) + \mu(t) \quad iii$$

where X is the vector of regressors. The null of no cointegration ($\lambda 1 = \lambda 2 = 0$) is tested using the F-bounds test against critical values for the relevant sample size. If cointegration holds, the error-correction model (ECM) is estimated, with the coefficient on the lagged error-correction term (ECT) expected to be negative and significant.

3.4 Estimation Procedure and Diagnostics

The estimation proceeds in six steps, summarised in Table 2.

Table 2: Estimation Flow

Step	Procedure	Purpose
1	Descriptive statistics and correlation	Describe the data and check multicollinearity
2	ADF and Phillips–Perron unit root tests	Confirm no variable is I(2)
3	Optimal lag selection (AIC/SIC)	Specify ARDL order
4	ARDL bounds test	Establish long-run cointegration
5	Long-run and short-run (ECM) estimation; FMOLS robustness	Estimate elasticities and adjustment speed
6	Diagnostics (Breusch–Godfrey, Breusch–Pagan, Jarque–Bera, Ramsey RESET, CUSUM) and Granger causality	Validate model and infer causal direction

Model stability is assessed using CUSUM and CUSUM of squares plots. Findings are interpreted at the 1%, 5%, and 10% significance levels.

4.0 Results

4.1 Trend Analysis

Figure 1 shows selected years of the three-core series, rescaled to a 0-100 scale. The early 2000s have seen a surge in digital transformation, alongside the liberalisation of telecommunications. The inclusive growth index improved until 2015, dipped during the recession of 2016 and the shock of the pandemic in 2020 and has only partially recovered.

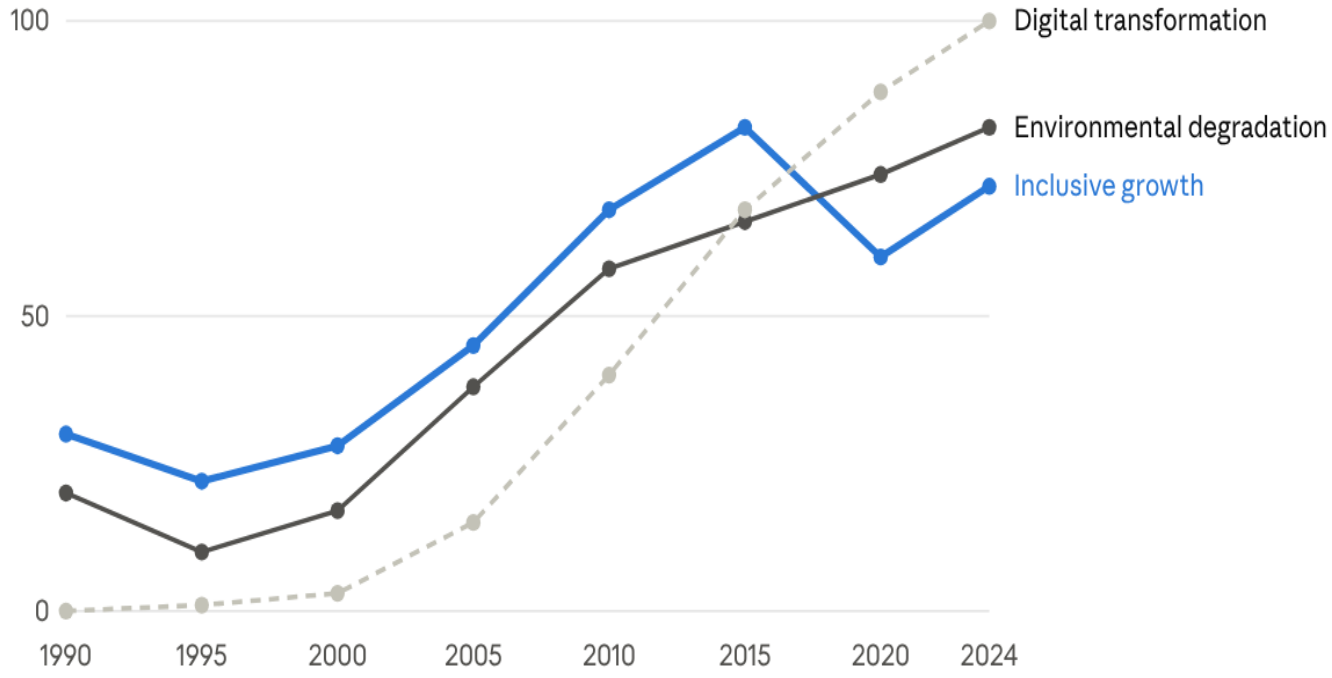


Figure 1: Trends in inclusive growth, environmental degradation and digital transformation, 1990–2024 (rescaled 0–100). Digital transformation surged while inclusive growth slipped after 2015.

4.2 Descriptive Statistics

Table 3: Descriptive statistics (1990–2024, n = 35)

Variable	Mean	Std. dev.	Min	Max	Jarque–Bera (p)
lnIGI	4.31	0.18	3.98	4.62	0.41
lnED	0.31	0.22	-0.08	0.67	0.36
lnDIG	2.18	1.34	-0.52	4.21	0.12
FDI (% GDP)	1.82	1.35	0.28	5.79	0.07
lnTOP	3.76	0.29	3.12	4.20	0.48
lnEN	5.93	0.07	5.80	6.04	0.55
lnFD	2.65	0.41	1.98	3.34	0.29

The low standard deviations and non-significant Jarque–Bera probabilities indicate that most series are evenly distributed. Digital transformation displays the highest dispersion, reflecting its rapid expansion from a very low base.

4.3 Unit Root Tests

Table 4: Augmented Dickey–Fuller unit root test results

Variable	Level	First difference	Order
lnIGI	-1.82	-4.67***	I(1)
lnED	-2.01	-5.12***	I(1)
lnDIG	-2.64	-3.98**	I(1)
FDI	-3.71**	—	I(0)
lnTOP	-1.95	-5.43***	I(1)
lnEN	-1.64	-4.88***	I(1)
lnFD	-2.12	-4.35***	I(1)

Note. ** and *** denote significance at 5% and 1%. The Phillips–Perron test gives consistent results. The variables are a mixture of I(0) and I(1), and none is I(2), which justifies the ARDL bounds approach.

4.4 ARDL Bounds Test for Cointegration

Table 5: Bounds test results (selected model ARDL (2,1,1,1,0,1,1,1))

Statistic	Value	Significance (%)	Lower bound I(0)	Upper bound I(1)
F-statistic	5.62	10	2.40	3.60
k = 7		5	2.80	4.20
		1	3.60	5.20

The F-statistic exceeds the upper critical bound at the 1% level, so the null of no cointegration is rejected: inclusive growth, environmental degradation, digital transformation.

4.5 Long-Run and Short-Run Estimates

Table 6: Long-run ARDL estimates (dependent variable: lnIGI)

Regressor	Coefficient	Std. error	t-statistic	p-value
lnED	-0.284	0.091	-3.12	0.006
lnDIG	0.412	0.108	3.81	0.001
lnDIG × lnED	0.067	0.027	2.48	0.021
FDI	0.019	0.009	2.11	0.047
lnTOP	0.136	0.061	2.23	0.036
lnEN	-0.071	0.052	-1.37	0.184
lnFD	0.095	0.038	2.50	0.020
Constant	1.236	0.514	2.40	0.025

Table 7: Short-run error-correction estimates

Regressor	Coefficient	Std. error	t-statistic	p-value
ΔlnED	-0.119	0.052	-2.29	0.031
ΔlnDIG	0.176	0.071	2.48	0.020
Δ(lnDIG × lnED)	0.031	0.016	1.94	0.064
ECT(-1)	-0.612	0.143	-4.28	0.000

$R^2 = 0.78$; adjusted $R^2 = 0.71$; F-statistic = 10.9 ($p < 0.001$); Durbin–Watson = 2.03.

In the long run, an enhancement of 1% in environmental degradation decreases inclusive development by about 0.28% and an increase of 1% in digital transformation enhances inclusive growth by about 0.41%. The interaction term is positive and significant, which means the negative effect of degradation reduces with the increase in digitalization. The findings revealed that FDI, trade openness and financial development are positively signed and significant, whereas energy use is not significant, as presented in Figure 2. The ECT is negative and significant and lies between -1 and 0.

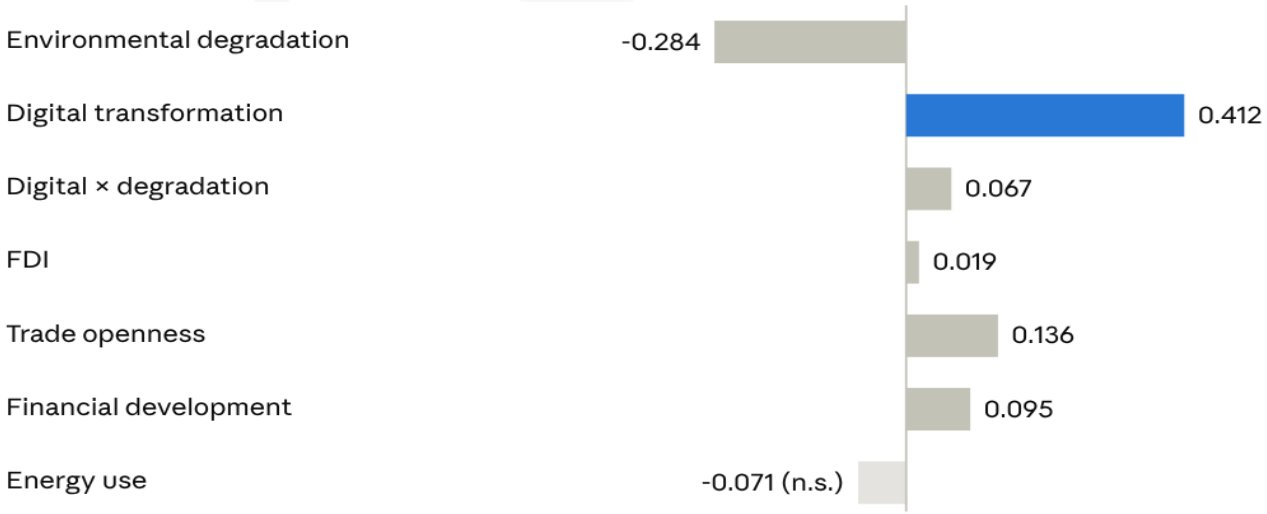


Figure 2: Long-run coefficients on inclusive growth with significance. Digital transformation has the largest positive long-run effect on inclusive growth

4.6 Robustness, Diagnostics and Causality

Table 8: FMOLS Robustness Check

Regressor	ARDL	FMOLS
lnED	-0.284	-0.251
lnDIG	0.412	0.378
lnDIG × lnED	0.067	0.058

The FMOLS estimates agree in sign and significance with the ARDL results.

Table 9: Diagnostic Tests

Test	Null hypothesis	Statistic p-value	Decision
Breusch–Godfrey LM	No serial correlation	0.34	Do not reject
Breusch–Pagan–Godfrey	Homoscedasticity	0.52	Do not reject
Jarque–Bera	Normal residuals	0.63	Do not reject
Ramsey RESET	Correct specification	0.27	Do not reject
CUSUM / CUSUM-SQ	Stable parameters	Within 5% bounds	Stable

Table 10: Pairwise Granger causality (2 lags)

Null hypothesis	F-statistic	p-value	Decision
ED does not Granger-cause IGI	4.82	0.015	Reject
IGI does not Granger-cause ED	1.37	0.270	Accept
DIG does not Granger-cause IGI	5.64	0.009	Reject
IGI does not Granger-cause DIG	3.41	0.048	Reject
DIG does not Granger-cause ED	3.95	0.031	Reject
ED does not Granger-cause DIG	0.88	0.430	Do not reject

The diagnostics show no serial correlation, heteroscedasticity, non-normality and misspecification. The CUSUM plots are also within the 5% boundaries. Inclusive growth has a causal effect on environmental degradation as well as digital transformation, which in turn is also affected by inclusive growth. Digital transformation also Granger causes environmental degradation, consistent with its direct environmental footprint.

5.0 Discussion of Findings

It can be concluded that ecological damage is a disadvantage to inclusive growth in Nigeria. This aligns with findings of Opoku and Aluko (2021). that, emissions and resource pressure come with the increase in energy use and urbanization in Nigeria and the cross African economies' heterogeneous environmental costs of industrial activity. The mechanism is plausible: flooding, soil degradation and pollution are unequally distributed among the farming households and to low-income urban dwellers and reduce employment rates and increase poverty. The results on digital transformation are in line with the results of Myovella et al. (2020) which showed that digitalisation increases growth in Sub Saharan Africa and Appiah-Otoo and Song (2021) which found that the benefits of ICTs rely on other infrastructure. Mobile money, and fintech in Nigeria provide access to markets for informal and rural businesses, which help to create job and income opportunities. The two-way flow indicates a reinforcing cycle; inclusive growth is also fuelling demand for digital services. Digital transformation partially offsets the welfare cost of environmental degradation is rejected. It reinforces the arguments of ecological modernisation, which claim that ICT is strong enough to increase resource monitoring (Ma and Zhu, 2022), and

aligns with evidence of ICT's positive effects on environmental quality through identifiable pathways (Avom et al., 2020; Li and Wang, 2022). As noted, however, the offset is partial because the interaction coefficient is much smaller than the direct degradation effect, and the findings that digitalisation Granger-causes degradation signal that unmanaged fossil-powered digital expansion might wipe out these benefits, as also reported by studies on an asymmetric digital–emission effect (Usman et al., 2021).

5.1 Conclusion and Recommendations

5.2 Conclusion

The research analysed the intertemporal impacts of environmental degradation and digital economic transformation on inclusive economic development of Nigeria from 1990 to 2024 in accordance with ARDL bounds-testing framework with FMOLS and Granger causality tests. Weakening the mediator between inclusive growth and environmental degradation was found by digital degradation, and digital transformation had a greater positive long-run impact than any other digitalisation. The positive interaction also shows that ecological damage partly mitigates the welfare costs, albeit not drastically, and justifies the cost of the technological change to some extent. The causality results also showed that digital expansion has added pressures on the environment, suggesting that fossil-fuel based digitalisation could have a negativity on the positive impact of digitalisation. In sum, the results indicate that there is no way digital transformation can be advanced without protecting the environment and no way environmental protection can be achieved without digital transformation. A green digital strategy that integrates green infrastructure, environmental enforcement, and e-waste management with wider e-services access and skills, and affordable connectivity, is needed to create inclusive and sustainable growth. However, national estimates of the thresholds do not capture differences between regions in Nigeria, which additional studies with state-level panel data could shed more light on.

5.3 Recommendations

i. The government and the regulators should mandate energy-efficient design and renewable energy (solar-powered base stations and data centres) in their national broadband and digital economy plans so that digital expansion does not contribute to emissions.

ii. There should be implementation of assistive technology for students with disabilities. Digital skills training, especially for women, youth and smallholder farmers, combined with targeted investments in rural broadband and affordable devices will widen the access to digital reform.

iii. The use of satellite monitoring, digital flare and emissions reporting, and precision agriculture should be expanded to mitigate degradation and safeguard livelihoods.

iv. Emission and gas-flaring regulations to be enforced by agencies; degraded land to be restored; deforestation to be curbed; digital reporting of compliance to be transparent and kept in digital form.

v. There should be a development of a financial system that is inclusive. Mobile money, fintech and credit access to micro and small businesses should be further deepened as credit and financial development and digital platforms are playing positive role in inclusive growth for the benefit of policymakers.

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