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Information and Communications Technology Penetration and Environmental Sustainability in Sub-Saharan Africa

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ABSTRACT

Africa's information and communication technology (ICT) expansion, especially in mobile phone use, has been substantial; nonetheless, it falls behind in internet accessibility and has environmental sustainability issues, such as climate change and pollution. This study investigates the nexus correlation between ICT penetration and environmental sustainability in Sub-Saharan Africa, using data from the World Bank and utilising a Panel Generalised Method of Moments analysis. Research demonstrates that ICT, as seen by mobile phone utilisation, has a positive correlation with CO_2 emissions in Sub-Saharan Africa. Nonetheless, ICT has opportunities for promoting environmental sustainability via creative solutions, such as mobile money systems and energy-efficient assets. The research highlights the need to tackle infrastructural and cost issues, advancing national ICT efforts, and implementing sustainable practices, such as energy-efficient hardware and life-cycle asset assessments. Policymakers are urged to use ICT as a strategic instrument to address environmental concerns and attain sustainability in the area.

Keywords: Information and Communications Technology, Technology, Environmental Sustainability, SSA, Poverty
JEL Classifications: O13, Q5, Q56

1. INTRODUCTION

Africa has experienced significant growth in Information and Communications Technology (ICT), particularly in mobile phones and internet accessibility, post-2020. Although more than 60% of Africans currently have a mobile phone, the continent lags behind other emerging countries in terms of internet access and usage (Aker and Cariolle, 2023). Environmental sustainability, as defined by the United Nations Environment Programme, involves adopting choices that guarantee future generations possess a similar or superior quality of life.

Although it may not be widely acknowledged, the UN's definition is widely accepted and has been updated over time to take into account perspectives on human needs and well-being, including non-economic factors like education and health, clean air and water, and the preservation of natural asset (Alnsour, 2024). The loss of biodiversity, environmental harm, the dumping of plastic waste into the oceans, and climate change are all current issues with relation to environmental sustainability in the modern world (Kolawole and Iyiola, 2023).

Lack of environmental sustainability in Sub-Saharan Africa and increase in carbon emission has led to climate change, which causes insufficient and unreliable rainfall that changes weather patterns or causes flooding leading to the difficulties in carrying out businesses. Even the existing waters (oceans, river, streams and lakes) are being polluted and can no longer be used. It has had an impact on Africans and their already fragile food systems (Mishra, 2023). The population of Sub-Saharan Africa is projected to increase from 700 million in 2007 to 1 billion by 2030 and 1.5 billion by 2050, accompanied by urbanisation expansion.

Excluding the anticipated rise in per capita demand for food and water, worldwide water consumption is projected to more than quadruple in the first half of the twenty-first century.

About three-quarters of Africa's population depends on agriculture for a living, and much of it is rain-fed. Extreme and protracted droughts, flooding, and the loss of arable land owing to desertification and soil erosion are endangering rural and pastoralist populations by lowering agricultural output, resulting in crop failure and animal loss (Safi et al., 2024). The pastoralist regions of the Horn of Africa (near the borders of Ethiopia, Kenya, and Somalia) have been severely affected by ongoing droughts. Additionally, biodiversity is lost as a result of pollution brought on by carbon emissions. This has led to many forms of unemployment and poverty. Only 3.8% of the world's greenhouse gas emissions are produced in Sub-Saharan Africa, compared to 23% in China, 19% in the US, and 13% in the EU. However, climate change is particularly vulnerable to them (Manasseh et al., 2024).

There is a dearth of studies capturing how ICT (mobile phones) in Sub-Saharan Africa affect CO_2 intensity. This is worrisome given that in just 2020, carbon emissions was 823,770.02 which has a 2.75% increase in 2021 (World Bank, 2020). Furthermore, prior studies have focused on examining the connection between energy usage, CO_2 emissions, and economic growth (Jebabli et al., 2023; Kartal et al., 2024; Dilanchiev et al., 2024).

As initiatives for sustainable economic development and worldwide environmental awareness increase, businesses are shifting their priorities to include environmental sensitivity (Hariram et al., 2023). Business as usual is clearly no longer the reality, as evidenced by government regulations, public pressure groups, and green consumer pressure. Due to a lack of flexibility, limited scope of information, and comprehension, previous research only showed relationships between energy consumption, CO_2 emissions and economic growth but lacked a policy focus on how to provide solution or curb the increase of CO_2 emissions.

The region's increasing ICT adoption has opened up new opportunities for social, economic, and educational development, with mobile money services and e-learning platforms providing financial services to millions who previously had no access to conventional banking. To accelerate ICT penetration, more funding is needed for digital infrastructure and policies to close the digital divide. Also, the continent has a large and energetic young population that is ravenous when it comes to ICT gadgets and services. While ICT penetration in developed and emerging countries is approaching saturation level, it is thriving and has high penetration potential in the African continent (Bello et al., 2023). Additionally, the fast expansion of ICT in Africa might help the poor lift themselves out of poverty and seize life's bounty of chances. Would the fast expansion of ICT and the influx of foreign direct investment (FDI) be able to work together to help SSA nations attain the SDGs?

The effect of establishing ICT on the environmental sustainability of sub-Saharan African nations is the focus of this research, lending credence to the ever growing discuss of achieving sustainable development growth by focusing on SGD 13 (climate action). Also, the highlighted Gap in this research is using ICT as policy variable or strategy. Therefore, we research how ICT penetration (mobile phone usage) can impact environmental sustainability in sub-Saharan Africa.

2. LITERATURE REVIEW

2.1. Conceptual Review

2.1.1. Environmental sustainability

Environmental sustainability and environmental accounting are closely intertwined concepts that contribute to the overall goal of achieving a more sustainable future for our planet in spite of organizational, business and industrial activities. Environmental accounting provides tools and methodologies to measure, quantify, and report on the environmental impacts of organizations (Gonzalez and Peña-Vinces, 2023). This information is crucial for understanding the sustainability of business practices and identifying areas for improvement. By integrating environmental performance indicators into their accounting systems, organizations can track and manage their environmental impacts more effectively, leading to better-informed decision-making (Bebbington et al., 2023).

However, environmental accounting enables organizations to evaluate the costs and benefits associated with their environmental initiatives. By assessing the financial implications of sustainability measures, organizations can identify opportunities for cost savings, resource efficiency, and waste reduction (Cheng et al., 2024). This analysis helps align environmental goals with economic objectives, making sustainable practices more economically viable. Through environmental reports and disclosures, organizations can communicate their sustainability efforts and achievements, building trust and credibility with stakeholders. This communication fosters engagement, collaboration, and collective action towards shared environmental goals.

Furthermore, environmental accounting facilitates the evaluation of an organization's environmental performance over time (Bresciani et al., 2023). By establishing environmental benchmarks and targets, organizations can monitor their progress, identify trends, and implement strategies to improve their sustainability performance. This evaluation encourages continuous improvement and accountability in environmental management. Environmental accounting supports environmental sustainability by integrating environmental considerations into decision-making processes, promoting resource efficiency, encouraging transparency and accountability, and facilitating the alignment of economic and environmental objectives. It enables organizations to understand the environmental impacts of their activities, make informed choices, and work towards a more sustainable future (Adelakun et al., 2024).

2.1.2. ICT penetration

ICT penetration into Africa refers to the adoption and utilization of information and communication technology (ICT) infrastructure, services, and applications across the African continent (Van-Zanden, 2023). Over the past decade, Africa has experienced significant growth in ICT penetration, although there are still variations between countries and regions. The penetration of ICT into the sub-Saharan Africa have greatly reduced the carbon emission as transaction and travelling costs that are associated with the CO_2 emissions in households and corporations are conducted over the internet and mobile phones (Gander and Panicker, 2025).

Mobile technology has been instrumental in driving ICT penetration in Africa. Mobile phone usage has skyrocketed across the continent, surpassing traditional landline infrastructure. Mobile networks provide voice communication, messaging services, and internet access to a large segment of the population, even in remote areas. Mobile money platforms, such as M-Pesa in Kenya, have transformed financial services and expanded access to banking and payment (Ahmed et al., 2021).

The availability and affordability of internet access have improved in Africa, although there are still challenges in rural and underserved areas. The expansion of mobile internet, the growth of submarine fiber optic cables connecting Africa to the global internet backbone, and the development of terrestrial broadband infrastructure have contributed to increased connectivity. However, the digital divide remains a concern, with discrepancies in internet access between urban and rural areas (Arion et al., 2024). Despite progress, several challenges remain in expanding ICT penetration in Africa. These challenges include inadequate infrastructure, high costs of connectivity, limited digital skills, and addressing the digital divide between urban and rural areas. However, these challenges also present opportunities for investment, innovation, and collaboration to bridge the gap and unlock the full potential of ICT in Sub-Saharan Africa.

2.1.3. Mobile phones

Mobile phones are products of ICT that enable users to surf the internet, make calls, send and receive text messages and perform all other types of electronic communication activities. It is a well-known fact that the use of mobile phones has promoted environmental sustainability, but it is unfortunate that they have drawbacks as well (Iram et al., 2024). As a product of ICT, using a smartphone contributes to climate change and, ultimately, failure to achieve environmental sustainability (Kogler et al., 2024). According to Canadian researchers from McMaster University, smartphone use is now significantly more carbon-intensive than PC and laptop use in terms of carbon emissions. From 17 megatons per year to 125 megatons per year, they increased their CO_2 emissions. That is an increase of 730%. In 2020, there will be 7.7 billion mobile phones in use, with a carbon footprint of around 580 million tonnes of CO_2e. This accounts for just 1% of global emissions, but as more people have cell phones, this proportion is anticipated to rise (Li et al., 2024).

2.1.4. Internet

In today's world, we can share videos, images, messages, download music, stream videos, etc., at the touch of one button, all thanks to the internet, but with all this comes a cost. A few grammes of carbon dioxide are emitted since your wireless networks and gadgets require energy to operate (Bonab et al., 2024). Although less obvious, the enormous servers and data centres needed to power the internet and archive the content we access through it may even consume more energy (Takci et al., 2025). Although sending an email or doing a single internet search consumes a little amount of energy, about 4.1 billion individuals, or 53.6% of the global population, now use the internet. When little energies are amalgamated, they provide a significant outcome. Estimates suggest that the carbon footprint of contemporary technology, including the internet and its supporting systems, accounts for 3.7% of global greenhouse gas emissions. Mike Hazas, a researcher at Lancaster University, asserts that it is analogous to the volume generated globally by the aviation sector. Furthermore, these emissions are anticipated to increase by 2025 (Ajibola et al., 2025).

2.2. Theoretical Review

Numerous theories seek to examine the ICT-sustainability nexus. The theoretical framework of this study is drawn from the epistemic community theory, which Peter Haas propounded. The theory explores the role of knowledge, expertise, and shared beliefs in shaping policy-making processes and outcomes (Park et al., 2022). It focuses on the influence of specialized knowledge communities on international and domestic policy-making, particularly in areas that involve complex scientific, technical, or policy-related issues. The theory suggests that these epistemic communities can play a crucial role in defining problems, proposing solutions, and shaping policy agendas. They can operate at both national and transnational levels. They often form transnational networks to share information, collaborate on research, and coordinate their policy advocacy efforts across borders. These transnational networks enhance their collective knowledge, amplify their influence, and facilitate policy diffusion across countries.

Although the members of an epistemic community may come from different academic or professional backgrounds, they are connected by a set of shared traits that encourage collective improvement rather than mutual benefit. They refer to this as their "normative component" (Krogmann, 2025).

Accountants as part of epistemic communities can play a significant role in influencing CO_2 emissions and environmental sustainability, as they are responsible for developing and implementing robust measurement and reporting frameworks (Lehner and Kyriacou, 2023). They can design environmental accounting systems that capture and quantify CO_2 emissions and other environmental impacts accurately. By providing transparent and reliable data, accountants enable organisations to track their emissions and monitor their environmental performance. Accountants can conduct environmental audits to assess an organization's compliance with environmental regulations, identify areas of improvement, and verify the accuracy of environmental disclosures. Through rigorous auditing processes, accountants contribute to maintaining the integrity and credibility of environmental information.

Epistemic communities can play a significant role in influencing environmental sustainability by identifying and defining environmental problems. Through their expertise and research, they can raise awareness about emerging environmental issues, highlight the potential risks and consequences, and draw attention to the need for action. Being a set of people that interact with policy decision makers, they can generate policy recommendations based on their specialized knowledge and expertise by proposing evidence-based solutions, innovative approaches, and best practices to address environmental challenges. These recommendations can inform policy-making processes and shape the development of effective and sustainable environmental policies.

Thus, this study is anchored on epistemic community theory, as its major concern is to bring people who are well-versed in environmental issues and provide the best practices, standards, guidelines and procedures organization can follow in reporting and achieving environmental sustainability, even if the means following the IFRS sustainability standards.

2.3. Empirical Review

Research has been undertaken to examine the correlation between ICT adoption and environmental sustainability in sub-Saharan Africa, Pakistan, and South Asia. Several studies (Naatu et al., 2025; Thierry et al., 2022; Anochiwa et al., 2022; Atsu et al., 2021) have investigated the relationship between ICT and diverse outcomes (financial development, electricity consumption, education, energy consumption, downsizing, energy security and social capital). However, a lack of consensus has resulted from these works of literature, which is likely due to variations in variables measured, sample sizes, methodology, research nations, and developmental stages.

While some research found a strong positive correlation between ICT and GDP growth, other studies found no correlation at all, while yet others found an indirect positive correlation. In their work on information technology (IT) policy design, Pradhan et al. (2015; 2018) suggested, for example, that a country's GDP grows when its ICT infrastructure is improved for broadband and internet users. On the contrary, Jorgenson et al. (2016) found that a slight portion of the fall in the growth rate in the United States during the great recession is associated with information technology-producing industries. However, these studies have not

In sub-Saharan Africa, ICT and the economic growth nexus have recently been examined (Haftu, 2018; Donou-Adonsou, 2019). Haftu (2018) evaluated the influence of mobile phones and the internet on the economic growth of Sub-Saharan Africa using the system generalized method of moments for a sample of 40 countries. A key component of the region's economic success, according to the results, has been the expansion of mobile phone usage. Likewise, in sub-Saharan Africa, Donou-Adonsou (2019) investigates the impact of information and communication technology infrastructure on GDP development in the context of high-quality education. The outcome demonstrates that nations with more educational opportunities benefit economically from the internet, but those with less access to education have no impact from mobile phones. The research in these studies omitted renewable energy sources and environmental indicators.

The work of Asongu et al. (2019) and Asongu et al. (2023) for sub-Saharan Africa which examines the effect of enhancing ICT facilities such as internet and mobile phone penetration on environmental sustainability, are closely related to this study. According to the former, there is a positive net effect of ICT infrastructure on CO_2 emissions, while there is a negative net effect of rising mobile phone penetration on CO_2 emissions from liquid fuel usage. Afterwards, it was noted that information and communication technology may help mitigate any detrimental effects of the environment on human progress. There is a vacuum in the literature since their research did not include renewable energy as part of the ICT-environmental sustainability nexus, even though their aim was quite similar to ours.

With a focus on sub-Saharan Africa, this research looks at how information and communication technologies have affected environmental sustainability. So far, the literature that has been consulted does not include energy usage as part of the ICT-SDG nexus. Nevertheless, by including it, we may better understand how ICT might be a valuable instrument for SDG policymaking.

3. METHODOLOGY

This study has been designed to use ex-post facto research, and the data were derived from the already established information in the World Bank database. This type of research design is considered most appropriate because of its cross-sectional approach that ensures to evaluation of the impact of ICT on environmental sustainability in sub-Saharan Africa. This study adopted the non-probability sampling in which the population units are selected at the discretion of the researcher. At the time of this study, the total countries number sub-Saharan Africa is 48, but for data accessibility, a sample size of 43 out of the 48 companies was chosen as a good representation of the sub-Saharan African countries emitting carbon emissions using the purposive sampling technique. The statistical method used to analyse the data for the purpose of this study includes both descriptive and analytical statistics. The analytical statistics include a panel generalised/ method of moments as the method of analysis and descriptive statistics, which describe the effect of ICT on environmental sustainability in sub-Saharan Africa. Also, descriptive statistics tests were carried out to understand the characteristics and normality features of the variables.

3.1. Model Specification

The model for this study was adapted to capture the interrelationships between the dependent variable and the independent variables. To estimate the effect of ICT penetration on the environmental sustainability in sub-Saharan Africa. The study adapted the model of Asongu and Acha-Anyi (2020).

$$CO_{i\,t} == \sigma 0 + \sigma 1\ CO\ I,t-\tau + \sigma 2\ M\ i,t + \sigma 3\ K\ i,t + \sigma 4 MK\ i,t + \sum_{h=1}^{5} \begin{pmatrix} \delta \\ h \end{pmatrix} x^{W} h^{i,i,t-r} \quad (1)$$

$$CO\ i,\text{-}\ COi,\ t-\tau = \sigma 1\ (COi,\ t-\tau - COi,\ t-\tau\ 2\tau) + \sigma 2\ (M\ i,t - Mi,\ t-\tau) + \sigma 3\ (K\ i,t - Ki,\ t-\tau) + \sigma 4\ (MK\ i,t - MKi,\ t-\tau) ++ + \sum_{h=1}^{5} \delta h\ (Wh,I,-r - Wh,I,-2r) + (Ui,t - Ui,t\text{-}r) \quad (2)$$

This study has modified the model as:

$$LNCO_2PC_{it} = \sigma_0 + \sigma_1 LNCO_2PC_{it-1} + \sigma_2 LNENG_{it} + \sigma_3 LNTRD_{it}$$

$$+ \sigma_4 LNENG_{it} + \sigma_5 LNFIN_{it} + \sigma_6 LNMOB_{it} + \sigma_7 LNGDP_{it} + \sigma_8 LNPOP_{it} + U_{it}$$

$$LNCO_2LF_{it} = \sigma_0 + \sigma_1 LNCO_2LF_{it-1} + \sigma_2 LNENG_{it} + \sigma_3 LNTRD_{it} + \sigma_4 LNENG_{it} + \sigma_5 LNFIN_{it} + \sigma_6 LNMOB_{it} + \sigma_7 LNGDP_{it} + \sigma_8 LNPOP_{it} + U_{it}$$

$$LNCO_2IT_{it} = \sigma_0 + \sigma_1 LNCO_2IT_{it-1} + \sigma_2 LNENG_{it} + \sigma_3 LNTRD_{it} + \sigma_4 LNENG_{it} + \sigma_5 LNFIN_{it} + \sigma_6 LNMOB_{it} + \sigma_7 LNGDP_{it} + \sigma_8 LNPOP_{it} + U_{it}$$

Where

CO_2PC_{it} = CO_2 emission per capita

CO_2LF_{it} = CO_2 emission per liquefied fuel

CO_2IT_{it} = CO_2 emission intensity

ENG_{it} = Energy consumption

TRD_{it} = International trade

FDI_{it} = Foreign direct investment

FIN_{it} = Financial development

MOB_{it} = Mobile phone subscription

GDP_{it} = Gross domestic product

POP_{it} = Population

i is the cross-section dimension and ranges from 1 to n/number of periods.

t is the time series dimensions and ranges from 1 to t/number of countries.

σ = constant

ξ = time-specific constant

η = country-specific effects (or factors that are particular to each country in the sample),

$U_{i,t}$ = two-way disturbance term and ε is the error term.

3.2. Measurement of Variables

Definition and measurement of variables are presented in Table 1.

4. DATA ANALYSIS AND INTERPRETATION

4.1. Descriptive Statistics

The dataset reveals significant variation and skewness, particularly for CO_2IT, FDI and GDP (Table 2). Furthermore, most variables are left skewed except for CO_2LF, which is left skewed. Also, high standard deviation are noticed in variables such as GDP, POP and CO_2IT, suggesting high variability in the dataset from the mean. The Jacque-Bera test of the normality of all variables in the dataset does not follow a normal distribution. This goes ahead to justify the application of the GMM estimation technique.

4.2. Correlation Matrix

The Table 3 shows the correlation amongst the variables. It was carried out to test for multicollinearity amongst the independent variables with a benchmark of 80%. From the analysis, it can be seen there is a low level of multicollinearity. Also, according to the findings, there is a significant positive correlation between ENG and energy consumption, indicating that higher energy use results in higher CO_2 emissions per person. Nonetheless, there is a somewhat positive correlation with FIN, indicating that increased

Table 1: Definition and measurement of variables

S. No.	Variables	Variable type	Measurement	Sources
1	Liquid fuel carbon emission	Dependent variable	CO_2 emissions from liquid fuel consumption (% of total)	Word bank (WDI) (Asongu and Acha-Anyi, 2020)
2	Carbon emissions Per Capita	dependent variable	CO_2 emissions (metric tons per capita).	Okere et al. (2025)
3	Carbon intensity	dependent variable	CO_2 intensity (kg per kg of oil equivalent energy use)	Word bank (WDI)
4	Mobile phone	independent variable	Mobile phone subscriptions (per 100 people)	Word bank (WDI)
5	Foreign direct investment	Control variable	Foreign direct investment inflows (% of GDP)	Word bank (WDI) (Odhiambo, 2021)
6	Population	Control variable	Population growth rate (annual %)	Word bank (WDI)
7.	Gross domestic product	Control variable	Gross domestic product (GDP) growth (annual %)	Word bank (WDI)(Asongu, 2020)
8.	Energy consumption	Control variable	Energy usage	Word bank (WDI)
9.	International Trade	Control variable	Imports plus Exports of goods and services (% of GDP)	Word bank (WDI)

Source: Authors Computation (2025)

Table 2: Descriptive Statistics Matrix

Variable	CO_2PC	CO_2LF	CO_2IT	ENG	TRD	FIN	MOB	GDP	POP	FDI
Mean	1.36	69.385	4.560	666.38	78.56	22.84	44.30	36648607	21201173	4.366
Median	0.40	75.750	1.150	420.5	71.00	14.804	30.00	13056852	10634073	2.40
Std. Dev.	2.200	26.23	16.65	695.40	37.69	26.85	45.15	82057167	31754099	8.77
Skewness	2.542	−0.731	5.545	1.996	0.950	3.055	0.892	3.77	2.83	9.86
Kurtosis	8.758	2.487	32.860	6.097	3.679	12.993	2.786	16.76	12.50	152.44
Jarque-Bera	1777.92	74.385	31454.09	791.668	123.85	4144.82	100.296	7629.54	3795.77	703437.4
Probability	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Observations	723	744	744	744	729	725	744	744	744	743

Source: Authors' Computation (2025)

CO_2 emissions are linked to financial development. Additionally, the study finds a negative correlation with CO_2LF, indicating that per capita emissions decrease as CO_2 emissions from liquid fuels increase.

4.3. Panel GMM Regression

In this section, the study employed a panel generalized method of moments to investigate the effects of ICT on environmental sustainability in sub-Saharan Africa.

Table 4 shows the results of the GMM analysis examining the relationship between ICT penetration and environmental sustainability in sub-Saharan Africa using three measures (CO_2PC, CO_2LF and CO_2IT) of environmental sustainability. The regression also tested by using diagnostic tests to ensure the validity of the instruments and model specifications.

A high degree of persistence in carbon emissions over time is indicated by the lagged dependent variable (Persistence of Emissions), which is positive and statistically significant at the 1% level. $LNCO_2PC$ (0.127) and $LNCO_2LF$ (0.175) emissions are greatly increased by energy consumption, indicating that increased energy use raises both per capita and fuel-based carbon emissions. It has a negative impact on LNCO2IT (−0.538), though, which might be a sign of structural changes in industrial energy efficiency or a move towards cleaner technologies.

$LNCO_2PC$ (0.153) and $LNCO_2IT$ (0.211) are positively and significantly impacted by trade openness, suggesting that higher emissions are linked to increased trade activity. It indicates that trade has a very small direct impact on emissions from liquid fuels, though, as it has no discernible effect on $LNCO_2LF$ ($P = 0.9593$).

Financial development affects emissions in a variety of ways; the $LNCO_2PC$ model shows negligible effects, the $LNCO_2LF$ model shows significant decreases, and the $LNCO_2IT$ model shows significant increases. $LNCO_2PC$ and $LNCO_2LF$ are negatively impacted by mobile subscriptions in a statistically significant but minor way, indicating that digitisation may aid in lowering emissions. While population growth has no statistically significant

Table 3: Correlation analysis

	Correlation									
Probability	CO_2PC	CO_2LF	CO_2IT	ENG	TRD	FIN	MOB	GDP	POP	FDI
CO_2PC	1.00									

CO_2LF	−0.46	1.000								
	0.00	-----								
CO_2IT	0.02	−0.32	1.00							
	0.65	0.00	-----							
ENG	0.85	−0.37	−0.14	1.00						
	0.00	0.00	0.00	-----						
TRD	0.35	−0.15	0.38	0.29	1.00					
	0.00	0.00	0.00	0.00	-----					
FIN	0.58	−0.33	−0.03	0.44	0.07	1.00				
	0.00	0.00	0.39	0.00	0.04	-----				
MOB	0.27	−0.08	0.03	0.28	0.14	0.34	1.00			
	0.00	0.03	0.49	0.00	0.00	0.00	-----			
GDP	0.39	−0.40	−0.07	0.31	0.26	0.52	0.17	1.00		
	0.00	0.00	0.05	0.00	0.00	0.00	0.00	-----		
POP	−0.05	−0.18	−0.13	0.02	−0.42	0.07	−0.00	0.76	1.00	
	0.13	0.00	0.00	0.58	0.00	0.08	0.99	0.00	-----	
FDI	0.07	0.09	−0.00	0.16	0.29	−0.05	0.03	−0.10	−0.10	1.00
	0.06	0.01	0.95	0.00	0.00	0.16	0.47	0.00	0.00	-----

Source: Authors' computation (2025)

Table 4: Two-step dynamic GMM and diagnostic test result

Variables	Dependent ($LNCO_2PC$)	Dependent ($LNCO_2LF$)	Dependent ($LNCO_2IT$)
$LNCO_2PC(-1)$	0.525894 (0.0000)	0.298842 (0.0000)	0.478828 (0.0000)
LNENG	0.126860 (0.0002)	0.175144 (0.0000)	−0.537671 (0.0020)
LNTRD	0.153037 (0.0000)	0.000555 (0.9593)	0.210823 (0.0000)
LNFIN	−0.008949 (0.2217)	−0.068575 (0.0000)	0.088760 (0.0056)
LNMOB	−0.009471 (0.0372)	−0.014609 (0.0000)	0.029145 (0.0168)
LNGDP	0.352782 (0.0000)	0.052947 (0.0373)	0.018278 (0.9080)
LNPOP	−0.070090 (0.2628)	0.003439 (0.9350)	0.188259 (0.5693)
FDI	0.002332 (0.0000)	0.000418 (0.0007)	−0.002270 (0.1446)
No. of observation	625	647	647
Wald Chi^2	2855.398 (0.0000)	20224.13 (0.0000)	84.32285 (0.0000)
AR (1)	NA	NA	−0.000019 (1.0000)
AR (2)	NA	−0.000791 (0.9994)	NA
J-statistics	26.24849 (0.289276)	24.42569 (0.437483)	21.28882 (0.621634)

Source: Authors' computation (2025)

impact on any of the emissions models, economic growth is a powerful positive driver of $LNCO_2PC$.

The dynamic GMM results conclude that carbon emissions are very persistent and that, depending on the source of the emissions, energy consumption, trade, GDP, financial development, and mobile technology all play different roles.

4.4. Discussion of Findings

From the above analysis, the study emphasises the necessity of early intervention to reverse emissions trends and the persistence of carbon emissions as a result of path dependency and structural inertia. Governments must give the switch to renewable energy top priority because the positive correlation between energy use and emissions points to a sustained reliance on fossil fuels. The detrimental effect of industrial emissions might be a sign that businesses are implementing cleaner technologies or increasing energy efficiency. Increased support is needed for clean energy adoption and industrial innovation.

Furthermore, higher emissions are linked to trade openness, indicating the necessity of environmental provisions in trade agreements. Green technology incentives should be incorporated into export-oriented industrial policies in order to reduce emissions. Capital can be directed towards low-carbon projects by coordinating financial development policies with green financing guidelines.

Also, Digitalisation may increase environmental consciousness and energy efficiency, indicating the need for more digital infrastructure to support green innovation, smart energy systems, and digital emissions monitoring. By encouraging eco-innovation and moving towards low-carbon industries, GDP growth should become more environmentally friendly. Instead of population control, population growth should concentrate on production methods and consumption trends.

Consequently, Fuel-based emissions and per capita emissions are positively correlated with financial direct investment (FDI), indicating that high-emission industries may still be the focus of investment inflows. It is essential to create FDI incentives that penalise carbon-intensive projects and give preference to clean industries.

5. CONCLUSION AND RECOMMENDATION

The research reveals the relationship between ICT and environmental sustainability in sub-Saharan Africa. As a stand-in for ICT penetration, mobile phone subscriptions have a major effect on carbon emissions, according to the dynamic GMM estimation. Negatively, through better communication, more intelligent transportation and energy use, and digital innovations, greater ICT penetration may lower emissions per capita and emissions from the use of liquid fuels. On the other hand, the energy requirements of ICT infrastructure and the rise of digital industries that might not be completely decarbonised could lead to an increase in industrial emissions as a result of ICT expansion.

According to these results, ICT adoption may have two effects on the environment: it may lower emissions in sectors related to consumption, but if clean energy and sustainable digital infrastructure are not provided, it may raise emissions in industrial applications. Supporting green ICT infrastructure, using ICT for environmental monitoring and efficiency, incorporating ICT into climate policy, creating regulatory frameworks for sustainable digitalisation, encouraging innovation and investment in green tech, and fostering cross-sector collaboration between the energy, environmental, and ICT sectors to develop scalable low-emission technologies are some suggestions for maximising the environmental benefits of ICT while minimising its negative effects.

In conclusion, the widespread use of mobile phones and ICT offers a significant chance to lower carbon emissions, particularly in non-industrial sectors. However, the expansion of ICT might unintentionally lead to an increase in industrial emissions if intentional measures are not taken to decarbonise the digital ecosystem. To optimise ICT's green potential while controlling its environmental impact, a well-rounded, progressive policy approach is necessary.

This study emphasises the necessity of early intervention to reverse emissions trends and the persistence of carbon emissions as a result of path dependency and structural inertia. Governments must give the switch to renewable energy top priority because the positive correlation between energy use and emissions points to a sustained reliance on fossil fuels. The detrimental effect on industrial emissions might be a sign that businesses are implementing cleaner technologies or increasing energy efficiency. Increased support is needed for clean energy adoption and industrial innovation.

Furthermore, higher emissions are linked to trade openness, indicating the necessity of environmental provisions in trade agreements. Green technology incentives should be incorporated into export-oriented industrial policies in order to reduce emissions. Capital can be directed towards low-carbon projects by coordinating financial development policies with green financing guidelines. Digitalisation may increase environmental consciousness and energy efficiency, indicating the need for more digital infrastructure to support green innovation, smart energy systems, and digital emissions monitoring. By encouraging eco-innovation and moving towards low-carbon industries, GDP growth should become more environmentally friendly. Instead of population control, population growth should concentrate on production methods and consumption trends.

Also, Fuel-based emissions and per capita emissions are positively correlated with financial direct investment (FDI), indicating that high-emission industries may still be the focus of investment inflows. It is essential to create FDI incentives that penalise carbon-intensive projects and give preference to clean industries.

Based on the study's findings, the following suggestions can be summed up;

i. Political decision-makers can have an impact by addressing issues like affordability and a lack of internet infrastructure that are related to internet penetration.
ii. Other African nations should push national initiatives like the Rwanda Information Technology Authority (RITA). RITA

combines and coordinates national information technology resources.

iii. Energy-efficient hardware and smart transportation systems should be adopted.

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