

Article

Decomposing the Persistent and Transitory Effect of Information and Communication Technology on Environmental Impacts Assessment in Africa: Evidence from Mundlak Specification

Olatunji Abdul Shobande 

Business School, University of Aberdeen, Aberdeen AB243RX, UK; o.shobande.19@abdn.ac.uk;
Tel.: +44-743281-818-872

Abstract: This study examines the persistent and transitory effects of information and communication technology (ICT) on the environmental impact assessment in Africa. The applied advanced econometrics is based on both the Mundlak and Hausman–Taylor methodology for correcting endogeneity and the feasible generalized least squares (FGLS) method to identify any potential cross-panel correlation. The empirical evidence suggests that an increase in ICT (Internet penetration) has a positive transitory effect on the environment. On the contrary, an increase in ICT has a negative persistent effect on the environment. This implies that a temporary change in ICT usage increases carbon emissions, whereas ICT use can reduce carbon emissions in the long run. In addition, this study identified mediums through which ICT can affect the environment, such as energy consumption. Therefore, this study recommends continuous investment in ICT infrastructure and education on the importance of practicing environmentally sustainable practices. Similarly, energy conservation is critical because use of the Internet appears to indirectly increase energy usage by increasing the overall productivity of the economy, which may subsequently degrade the environment.

Keywords: ICT; carbon dioxides; environment; human capital; Mundlak specification; Africa



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1. Introduction

Concerns about environmental quality and human survival have increased as the demand for information and communication technology (ICT) has grown. The question is whether ICT can help delay the effects of climate change. This question has not been addressed in the existing research because the majority of studies are inconsistent and remain contentious. Previous studies have found no meaningful impact of ICT on the environment [1], and recent studies have found that ICT may help reduce carbon emissions and ensure sustainability [2–4]. To resolve these conflicting findings, this study empirically investigated whether the persistent and transitory effects of ICT may explain environmental and human impacts in Africa, with the hope of providing new knowledge that will ensure sustainability.

An empirical investigation is necessary for three reasons. First, ICT is an important tool for educating the new millennial generation on the future environmental and health risks associated with increasing carbon (CO₂) emissions per capita. Second, ICT usage is the best approach to embrace sustainable development practices. The educational sector is currently facing the challenge of keeping pace with technological innovation and realizing the possible benefits of reducing human carbon (CO₂) emissions per capita (i.e., reducing the threat of climate change on the global population). Third, this work provides educators and academics, who may be reluctant to modify their pedagogical methods of imparting knowledge regarding environmental sciences, with best practices to address anthropogenic climate change using ICT and promote environmental sustainability. Additionally, this research provides practical knowledge for policymakers in their efforts to mitigate the impacts of carbon emissions in both the transitory and persistent periods.

Many factors motivate the urgent need to assess the impact of ICT and the environment in Africa. First, the world is transitioning to a more competitive digitalized economy, which means that economic activity will likely increase, influencing energy demand [1,5–8]. For example, ICT has made it possible for several academic conferences to be held virtually, which means that energy use is likely to rise and might have a potential impact on the environment. As a result, further understanding of ICT use and its impact on the environment is essential for sustainability. Second, many homes have been converted to offices as more virtual office meetings are being conducted, implying the need for buildings with more efficient heating and cooling facilities and installed energy conservation systems, which have an impact on the environment [9–11]. Third, most businesses profit from ICT because of their cost-effectiveness. For example, ICT has ushered in newer technologies and shorter lead times. Capital spending appears to have become substantially more effective, enabling businesses to substitute capital for labor and other inputs [12–14]. Fourth, technology-based emerging industries have expanded dramatically as a result of ICT. For example, wireless infrastructure and the Internet have completely transformed the telecom and pharmaceutical industries; in the latter, the molecular biology revolution has made it impossible for traditional companies to retain their lead through new technology. In addition, ICT has improved the delivery of health services in terms of diagnostic instruments, medical devices, and surgical procedures. Fifth, ICT has not only ushered in the industrial revolution but has also improved people's social lives [8,15]. For example, social networking platforms such as Facebook and Twitter, and online dating services such as eHarmony and Match.com, have improved the social life of people; the music and publishing industries have also been transformed [4,5,16]. Although ICT plays a vital role in economic and social transformation, there is a serious concern that the growth in ICT might have an adverse effect on the environment, which creates the need to assess the mechanisms by which ICT affects the environment. Finally, numerous people, governments, and organizations are attempting to identify new and innovative ways to minimize energy demand and carbon emissions using existing and new ICT tools. The findings of this study will provide new information that will aid informed decision-making about ICT infrastructure investments that will help ensure their long-term viability.

Rather than pursuing a panel time-series approach, this study employed advanced panel econometric methods to determine whether the persistent and transitory effect of ICT can partially explain the impacts of climate in Africa. This study contributes to the following methodological advancements: (a) an extension and development of a Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) framework-based hypothesis for determining the relationship between ICT and carbon emissions; (b) a breakdown of the factors influencing persistent and transitory effects of ICT on environment using the Mundlak methodology; and (c) implementation of the Hausman–Taylor correction for endogeneity and feasible generalized least squares (FGLS) to verify the potential cross-panel correlation. The results of this study show that increases in ICT have a favorable and persistent impact on the environment.

This study adds to the theoretical papers seeking to address climate change by implementing the Mundlak methodology to assess the persistent and transitory effects of ICT on the African environment. Section 2 presents a concise summary of empirical and theoretical scholarly contributions with a comparison of the merits and limitations of their findings. Section 3 provides a detailed description of the data and methodology used in this study. Section 4 presents the results, discusses and compares the findings, and suggests policy implications. Section 5 concludes the study with suggestions and recommendations for further studies.

2. Literature Review

2.1. Theoretical Framework

The theoretical intuition that explains the link between ICT and environment is presented in the environmental Kuznets curve (EKC). The EKC predicts a decrease in carbon

emissions as the level of economic growth rises. Although long-term economic growth may be largely driven by technological innovation, there are concerns that technology has a cost on the environment. For example, increased Internet penetration can help lower production costs, but can also lead to higher energy usage, which might have a greater impact on carbon emissions. The EKC was considered for the present study because it provides yardsticks for assessing the indicators of environmental degradation. Therefore, the EKC serves as a theoretical framework because it is a purely empirical phenomenon that can help understand how technology affects the environment.

2.2. Empirical Evidence

Many researchers have reviewed the impact of ICT on environmental and human environments. For Africa, Asongu et al. [1] reviewed the impact of ICT on CO₂ emissions in 44 sub-Saharan African countries from 2000 to 2012. The study used the generalized method of moments and found no evidence of ICT affecting CO₂ emissions. Focusing on emerging economies using a panel mean group (PMG) and augmented mean group (AMG), Danish et al. [17] studied the effect of ICT on CO₂ emissions and discovered that ICT significantly affects CO₂ emissions. The novelty of this finding was the ability to capture the interaction term between ICT and gross domestic product (GDP), which resulted in the study's conclusion that development of ICT and GDP mitigate pollution levels. Using annual data from 1970 to 2014, Shahbaz et al. [11] examined whether globalization increased Japan's CO₂ emissions using an asymmetric threshold version of the autoregressive distributed lag (ARDL) model. Subsequently, the existence of a threshold asymmetric cointegration between the variables was confirmed. The study also indicates that threshold-based positive and negative shocks in carbon emissions result from increasing globalization.

In response to previous studies by Zhou et al. [18], by focusing on sector-level analysis in China, we examined how ICT influences carbon emissions using the Leontief model by integrating an input–output framework. Results indicated that the ICT sector significantly increases carbon emissions. In response to Zhou et al. [18], Khan et al. [19] focused on the impact of globalization, economic factors, and energy consumption on CO₂ emissions from 1971 to 2016, using the ARDL simulation model and data from Pakistan. Khan et al. [19] reported that urbanization, innovation, and economic growth have negative effects on CO₂ emissions. Similarly, Shahbaz et al. [10] investigated G7 countries and discovered that globalization increases CO₂ emissions.

The most recent literature consists of major theoretical papers assessing the role of human capital in the impact of ICT on CO₂ emissions. For example, Ahmed et al. [4] examined the criticality of ICT and human capital in environmental sustainability in Latin America and Caribbean countries from 1995 to 2017. Ahmed et al. [4] used continuously updated fully modified and continuously corrected updated bias-corrected methods and reported that ICT and globalization increase CO₂ emissions. Amri et al. [20] investigated the impact of ICT and total factor productivity on CO₂ emissions for the period 1975–2014 and found no evidence suggesting significant impacts of ICT on carbon emissions in Tunisia. Nguyen et al. [21] observed the effect of ICT on emissions in 13 selected G20 countries and reported that ICT does not increase CO₂ emissions.

A cursory look at the existing empirical evidence provides contradictory evidence. One common reason for the inconsistent and controversial findings is variation in the methodologies used to analyze these theoretical papers. This makes it difficult for policy-makers to respond appropriately. For example, Danish and Ahmed [17] used the PMG and AMG and found evidence of significant effects of ICT on carbon emissions. In contrast, Asongu et al. [1] used the generalized method of moment and found no evidence of ICT affecting carbon emissions. To address these problems, this study used more sophisticated and advanced econometric techniques based on the Mundlak methodology, which provides the additional information needed to resolve the problem.

2.3. Research Questions

In light of the above review, the research questions addressed in this study are as follows.

Question 1. *Is there an effect of ICT on the environment?*

Question 2. *Are there persistent and transitory effects of ICT on the environment?*

Answering these questions is important for Africa for numerous reasons: (a) Recent evidence has shown that Africa is likely to be significantly affected by climate change. Thus, understanding whether ICT can help mitigate or postpone the inevitable consequences of climate change can help the continent achieve sustainability and protect the existing and potential human capital. (b) The answer to the above research questions can help reveal the implications of ICT on the environment in both the transitory and persistent periods.

3. Data and Methodology

3.1. Data

This research investigates whether the persistent and transitory effects of ICT can explain environmental impacts using a panel of 32 Africa countries for the period 2000–2016. Consistent with the literature [14,15], the dependent variable is the environmental impact and is proxied with carbon emissions per capita. The ICT variable used is Internet penetration, which is consistent with previous studies [4,10,17]. To avoid omitted variable bias, the study controls other covariate variables, such as population growth and human capital variables (education and health). Consistent with the literature [5,22], the level of economic activity is proxied with energy consumption. All data were sourced from the World Development Indicators (World Bank), and greater detail of these variables is provided in Table 1. African countries investigated is listed in Appendix A, Table A1.

Table 1. Data and Sources.

Variables	Signs	Definitions	Sources
Environment impacts	CO ₂	CO ₂ emissions (metric tons) per capita	World Bank (WDI)
Technology	ict	Internet penetration (per 100 people)	World Bank (WDI)
Population	pop	Population growth rate (annual %)	World Bank (WDI)
Affluence	gdp	GDP per capita (constant 2010 US\$)	World Bank (WDI)
Education	edu	Pupil-teacher ratio in primary education	World Bank (WDI)
Human capital	health	Health expenditure per capita (constant US\$)	World Bank (WDI)
Energy consumption	energy	Energy use (kg of oil equivalent per capita)	World Bank (WDI)

Source: World Bank. WDI.

3.2. Methodology

3.2.1. Motivations

The intuition behind the persistent and transitory effects is based on the dynamic effects of environmental policy on ICT usage. The persistent–transitory specification of the equation reveals the time varying effect of ICT on environmental degradation without having to specify a lag structure. The specification is crucial given the shortcomings in previous empirical research, notably: (1) difficulties in lag selection; and (2) the unsettled issue of over-parameterization. The present study addresses these flaw by relying on the Mundlak [23] methodology to decompose the dynamic effects and make inferences regarding the cumulative impacts of ICT on the environment. Egger and Pfaffermayr [24] used a Monte Carlo simulation with the Mundlak methodology, and indicated that the approach can be viewed as an approximation of a general autoregressive distributed lag model. The Mundlak methodology can help to dissect the effects of ICT into two distinct effects. The first effect is the difference in average ICT usage, which is taken as the persistent effect. The second is the deviations from the mean of ICT usage, which is taken as the transitory effects. Additionally, the Mundlak method was extended to include the

Hausman–Taylor specification to address potential issues of selection bias, endogeneity, and measurement error in the sample.

3.2.2. Empirical Model

The study investigated the persistent and transitory effects of ICT on the environment in Africa using the stochastic STIRPAT paradigm, which summarizes the relationship between ICT and its environmental impacts. The framework proposed by Dietz and Rosa [25] measures the impact of human activity (I) on the environment. These factors are classified into three elements: population (P), affluence (A), and technology (T). The following reasons justify the use of the STIRPAT framework in this study. First, the STIRPAT framework can help evaluate the mechanism through which ICT can affect the environment. Second, the STIRPAT framework facilitates hypothesis decomposition and analytical research, which is critical for aggressive environmental policies aimed at reducing carbon emissions [26–28]. Third, the STIRPAT framework allows for the assessment of important anthropogenic factors, such as economic development, energy use, population, health, and awareness, which are likely to represent human activity in the environment [29,30]. Thus, the relationship is stated as follows:

$$I = f(P, A, T) \quad (1)$$

where I is an environmental impact proxy as carbon (CO_2) emissions per capita; P is a population proxy as population growth rate; A is an affluence proxy as per capita income; and T is a technology proxy with internet penetration.

3.2.3. Econometric Modelling

The model in Equation (1) is respecified econometrically from the stochastic function to the Mundlak specification as:

$$I_{i,t} = \eta P_{i,t}^{\phi_1} A_{i,t}^{\phi_2} T_{i,t}^{\phi_3} \mu_{i,t} \quad (2)$$

Taking the log of the stochastic function, the model becomes:

$$\log I_{i,t} = \eta + \phi_1 \log P_{i,t} + \phi_2 \log A_{i,t} + \phi_3 \log T_{i,t} + \mu_{i,t} \quad (3)$$

Equations (1) and (2) described and linearize the STIRPAT model. Next, we control for covariate variable that captures human capital. Drawing insight from Barro [31], human capital is represented by education and health, and the level of economic activity is captured with energy consumption (energy). Thus, the model becomes:

$$\log I_{i,t} = \phi_0 + \phi_1 \log P_{i,t} + \phi_2 \log A_{i,t} + \phi_3 \log T_{i,t} + \vartheta \log X_{i,t} + s_i + \mu_{i,t} \quad (4)$$

In our Model (4), X is a vector of other covariates, such as human capital, proxied as education and health; subscript i represents the country; t is time; ϕ_0 is a constant parameter ϑ ; ϕ_{1-4} represent the elasticity of the factors; and s and μ are unobserved factors of the error term, where the former is country specific. It is also assumed that s and μ are normally distributed, and the variance can be measured as:

$$s_i \sim N(0, \sigma^2)$$

$$\mu_{i,t} \sim N(0, \sigma^2)$$

Evidently, the above standard fixed-effect model can control the state-specific effects, but suffers from two important shortcomings. First, it assumes the state effect is constant over time; this assumption is unlikely to hold given the consistent change in environmental policy and socioeconomic factors [32,33]. Second, the effects of invariance are integrated, meaning it is unable to answer our research question. The alternative strategy is to use

a random effect to address this shortcoming, where s_i is used to account for the random factors. Unfortunately, the approach has the disadvantage [32,34–36] of assuming that:

$$E(s_i|X_i, P_i, A_i, T_i) = 0 \quad (5)$$

and this assumption is questionable. One approach to resolve this conflict is to follow the approach of Mundlak [23] which bridges the gap between the fixed and random effects, and enables us to decompose the factors into persistent and transitory effects. Thus, our model was respecified from Equation (5) as:

$$E(s_i|X_i, P_i, A_i, T_i) = \bar{X}_i \vartheta^m, \quad \phi^m (\bar{P}_i, \bar{A}_i, \bar{T}_i) \quad (6)$$

The ‘bar’ on the factor vectors represents the average or mean values of variables for each country, using the random effect form of Equation (5).

4. Empirical Results

This section presents the estimated models of the effect of ICT on the environment in Africa. The results were implemented using four advanced econometric methods, and the findings are discussed as follow.

4.1. Preliminary Check

The analysis began with the summary statistics of the variable which inform the prior behavior of the data used. The data were split into two groups, indicating the overall and state average of the samples, and the results of their preliminary checks are reported in Table 2.

Table 2. Summary statistics.

Variables	Overall Sample		State Average Sample		Observation
	Below/Min	Above/Max	Below/Min	Above/Max	
CO ₂	1.57	21.3	0.7	11.5	645
ict	3.3	34.4	0.03	20.2	622
pop	2.5	5.7	2.9	6.6	646
gdp	578	4105	177	1567	631
edu	14.6	27.3	13.01	43.01	690
health	4.5	19.5	6.8	12.3	484
energy	12.5	48.9	15.0	33.14	620

Notes: Carbon emission (CO₂), information and communication technology (ict), population (pop), gross domestic product (gdp), education (edu), human capital (health), energy consumption (energy).

According to the results, overall the minimum value of environmental impact (carbon (CO₂) emission per capita) is 1.57 metric tons per capita, whereas the maximum value is 21.3 metric tons per capita. For the state average, the minimum environmental impact is 0.7 tons per capita, whereas maximum is about 11.5 tons per capita. For Internet penetration (ICT), the overall minimum value is 3.3, whereas the maximum value is 34.4. For ICT at the state average, the minimum value is 0.03 and the maximum value is 20.2.

4.2. Results

As previously mentioned, the fixed effect (FE) model is the standard method used in panel analysis based on the assumption that the error term’s unobserved state-specific component is constant; the estimated FE is reported in Table 3.

Table 3 reports the fixed effects panel estimation for the 32 African countries. The empirical results in column 1 indicate a positive and statistically significant relationship between ICT and carbon emissions. This suggests that an increase in ICT will lead to an increase in carbon emissions. This result confirms the initial hypothesis and conforms to previous studies [4,18,19]. Column 2 of Table 3 presents the stochastic environmental factors, and the results indicate a positive and statistically significant relationship between population growth, per capita income,

energy, and carbon emissions. Column 3 of Table 3 includes other control of human capital (education and health), and the results show a negative and statistically significant relationship between education and health. This evidence suggests that an increase in education contributes to lower carbon emissions, whereas a corresponding increase in health improvement is expected to reduce carbon emissions. Similarly, the *F*-statistics results indicate the overall fit of the model was statistically significant at the 1% probability value, indicating ICT, population growth, income per capita, energy consumption, and indicators of human capital are determinants of carbon emissions (environmental degradation).

Table 3. Fixed effect model.

Independent Variable	Dependent Variable: CO ₂		
	(1)	(2)	(3)
ict	0.51 *** (3.98)	0.54 *** (4.32)	0.56 *** (4.45)
pop		0.06 *** (2.78)	0.07 *** (3.23)
gdp		0.0003 ** (2.92)	0.001 ** (1.86)
edu			−0.01 *** (−4.09)
health			−0.002 *** (−4.09)
energy			0.017 ** (2.51)
constant	18.65 ** (8.76)	16.12 ** (5.4)	18.01 ** (5.37)
country dummy	yes	yes	yes
F	15.85 ***	24.5 ***	20.85 ***
prob > F	[0.00]	[0.00]	[0.00]

Notes: Carbon emissions (CO₂), information and communication technology (ict), population (pop), gross domestic product (gdp), education (edu), human capital (health), energy consumption (energy). () is standard error, and [] represents the *p*-value. The coefficient estimates and their *t*-statistics are in parentheses for the period 2000 to 2016. ***, ** denote statistical significance at 1%, 5% levels, respectively.

4.3. Persistent and Transitory Effects of ICT on Environmental Impact Assessment in Africa

As earlier previously, the fixed effect is applied in empirical research, specifically when controlling for omitted variable bias [32,37–40], but has disadvantages. First, it assumes that the error is fixed, which is unlikely to hold due to climate policy change and socioeconomic dynamics. Second, it combines the effects of time-invariant factors, making it impossible to answer the presented research question. To circumvent these problems, the Mundlak [23] methodology, which is a compromise between the fixed effect (FE) and random effect (RE), was implemented; the results are reported in Table 4.

Table 4. Persistent and transitory effects of ICT on the environment, using the Mundlak methodology.

Independent Variable	Dependent Variable: CO ₂	
	Transitory (1)	Persistent (2)
ict	0.56 *** (4.5)	−0.14 (−0.05)
pop	0.07 *** (3.3)	−0.001 (−1.34)
gdp	0.001 ** (2.27)	0.005 *** (3.08)
edu	−0.01 *** (−4.23)	−0.019 (−0.94)
health	−0.0018 *** (−4.3)	−0.002 *** (−3.94)
energy	0.019 *** (3.12)	0.004 (0.13)
constant	18.73 *** (2.97)	30.4 (0.92)
F	43.24 ***	30.56 **
PROB > F	[0.00]	[0.00]

Notes: Carbon emissions (CO₂), information and communication technology (ict), population (pop), gross domestic product (gdp), education (edu), human capital (health), energy consumption (energy). () is standard error, and [] represents the *p*-value. The coefficient estimates and their *t*-statistics are in parentheses for the period 2000 to 2016. ***, ** denotes statistical significance at 1% and 5% levels, respectively.

The results in Table 4 column 1–2 show the coefficients of the persistent and transitory effects of ICT on environmental impact assessment. According to the results, an increase in ICT contributes to an increase in carbon emissions, and the coefficient and magnitude are

close to those of the estimated fixed effect panel. In contrast, no evidence of the persistent effect of ICT on the environment was found. Thus, the conclusion from the Mundlak specification is mixed.

4.4. Addressing Potential Problem of Endogeneity and Cross-Panel Correlation

The evidence from the Mundlak methodology appears to be mixed. Thus, it was imperative to assess our results against other specifications. To validate the results, the Hausman–Taylor statistical procedure for correcting endogeneity, which is widely used in empirical research [36,37,41], was implemented; the results are presented in Table 5.

Table 5. Persistent and transitory effects of ICT on the environment using the Hausman–Taylor specification.

Independent Variable	Dependent Variable: CO ₂	
	Transitory (1)	Persistent (2)
ict	0.56 *** (4.55)	−0.14 ** (−3.05)
pop	0.07 *** (3.68)	−0.001 ** (−2.34)
gdp	0.001 *** (3.9)	0.005 *** (3.10)
edu	−0.01 *** (−4.23)	−0.019 (−0.76)
health	−0.0018 *** (−5.5)	−0.002 *** (−3.94)
energy	0.02 *** (3.85)	0.004 ** (4.26)
constant	19.87 *** (3.7)	30.4 *** (2.92)
Wald χ^2	568 ***	453 **
prob > χ^2	[0.00]	[0.00]

Notes: Carbon emissions (CO₂), information and communication technology (ict), population (pop), gross domestic product (gdp), education (edu), human capital (health), energy consumption (energy). () is standard error, and [] represents the *p*-value. The coefficient estimates and their *t*-statistics are in parentheses for the period 2000 to 2016. ***, ** denote statistical significance at 1% and 5% levels, respectively.

Table 5 reports the transitory and persistent effects of ICT on the environment in Africa using the Hausman–Taylor correction. According to the results, after correcting for endogeneity, there is improved efficiency in the statistically significant level of the coefficient of the transitory effects and evidence is consistent. Interestingly, strong evidence was uncovered that indicates that ICT has a negative and persistent effect on carbon emissions. This implies that an increase in ICT can contribute to a long-lasting reduction in carbon emissions, whereas no evidence on the persistent effects of education was found.

4.5. Cross-Panel Correlation

In the preceding section, the issue of endogeneity was addressed using the Hausman–Taylor correction. Similarly, it is important to acknowledge that the potential cross-panel correlation cannot be ignored as it may significantly affect the analysis. Therefore, the feasible generalized least square (FGLS) was applied. Although the FGLS approach has its own disadvantages, several studies have suggested that it is better to implement FGLS than to assume cross-panel correlation is not present [41–45]. One major shortcoming of FGLS is if the number of periods, *T*, is smaller than the number of panels, there could be a potential problem of reduced efficiency [46,47]. To circumvent this problem, the bootstrap approach is applied when the dataset is large to construct an interval to estimate μ . For bootstrap distribution, 10,000 simulations were run, and our observations were drawn from the results. Interestingly, the interval coincided with the precision of both the normal and obtained bootstrap distributions.

Table 6 reports the persistent and transitory effects of ICT on the environment using the FGLS specification. After correction for cross-panel correlation, the estimated coefficient is considerably more reliable because nearly every coefficient is statistically significant at 1 percent. Similarly, the findings are consistent and robust. Thus, the analysis concludes that ICT has a negative long-lasting effect on the environment in Africa.

Table 6. Persistent and transitory effects of ICT on the environment using the FGLS specification.

Independent Variable	Dependent Variable: CO ₂	
	Transitory (1)	Persistent (2)
ict	0.51 *** (2.73)	−0.25 ** (−2.15)
pop	0.08 *** (2.94)	−0.02 *** (−3.14)
gdp	0.001 ** (4.24)	0.003 *** (3.44)
edu	−0.05 *** (−5.23)	−0.019 ** (−2.01)
health	−0.003 *** (−6.8)	−0.002 *** (−5.24)
energy	0.002 ** (7.11)	0.06 ** (5.62)
constant	23.5 *** (10.1)	28.4 ** (7.92)
Wald χ^2	723 ***	641 **
prob > χ^2	[0.00]	[0.00]

Notes: Carbon emissions (CO₂), information and communication technology (ict), population (pop), gross domestic product (gdp), education (edu), human capital (health), energy consumption (energy). () is standard error, and [] represents the *p*-value. The coefficient estimates and their *t*-statistics are in parentheses for the period 2000 to 2016. ***, ** denote statistical significance at 1% and 5% levels, respectively.

4.5.1. Answers to the Research Questions

The first research question sought to determine whether there was a link between ICT and the environment. According to the findings, ICT has both a positive and negative impact on the environment. The second research question examined the persistent and transitory effects of ICT on the environment. Based on the analysis, ICT has a long-lasting favorable impact on the environment. Specifically, consistent ICT use would help to minimize carbon emissions and protect the environment in the long run.

4.5.2. The implications of This Study Are as Follows

First, major ICT businesses must increase efforts to ensure the health of the environment. This can be accomplished by investing in green ICT infrastructure that reduces carbon emissions, resulting in a safer, healthier, and more sustainable environment. Second, the educational sector must integrate awareness about environmental protection and energy conservation methods into the curriculum, thus helping to reduce emissions. Third, it is essential to encourage development of artificial intelligence skills that can aid data management, energy conservation, and emission reduction. Fourth, the choice of energy source, Internet usage, and technology choice may have adverse effects on the environment. As a result, tightening of regulations related to energy usage and technology compliance should be a high priority. Fifth, ICT can help provide information on the environment, health, education, and energy management. Sixth, ICT can help promote two-way flow of information regarding demographics, social investment, and realization of sustainability.

5. Conclusions

This research investigates the persistent and transitory effects of ICT on the impacts of climate change in Africa. An advanced panel econometric approach, based on four statistical procedures, was implemented. The first statistical procedure was based on a standard fixed effect estimator. However, this method failed, and a second method was used based on the Mundlak methodology, which is a compromise identified within the random effect framework. The Mundlak method helps to classify the factors into persistent and transitory effects, and identify relationships among these. This allowed the investigation of the key research questions. The third approach was based on the correction for endogeneity proposed by Hausman and Taylor [48]. The fourth method was a robustness check that utilizes FGLS to test the potential cross-panel correlation problem. Our findings suggest that ICT transitorily contributes to an increase in carbon emissions, whereas additional evidence suggests that ICT can contribute to long-lasting progress towards environmental sustainability by mitigating the effect of carbon emissions. Thus, the study recommends continuous investment in ICT infrastructure and education regarding the importance of implementing environmentally sustainable practices. Similarly, energy

conservation is critical because the Internet appears to indirectly increase energy usage by increasing the overall productivity of the economy, which may subsequently degrade the environment. Finally, ICT is a potential enduring solution to enable e-sustainability and to increase awareness of the potential danger of poor environmental management.

This study used a STIRPAT-based approach, which offers an improved understanding of environmental sustainability and widespread technological innovation. This study is the first to implement an empirically driven statistical procedure based on the Mundlak methodology to estimate the persistent and transitory environmental impacts of ICT in Africa.

Future research should focus on how ICT can be used to reduce costs, boost efficiency, and foster long-term sustainability.

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Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. African Countries Examined.

African Countries Examined							
1	Angola	9	Cape Verde	17	Lesotho	25	Rwanda
2	Benin	10	Central Africa Republic	18	Ethiopia	26	Malawi
3	Botswana	11	Chad	19	Gabon	27	Ghana
4	Burkina Faso	12	Congo Democratic Rep.	20	Niger	28	Guinea
5	Burundi	13	Guinea-Bissau	21	Namibia	29	Mali
6	Cameroon	14	Kenya	22	Nigeria	30	Mauritania
7	South Africa	15	Sudan	23	Togo	31	Uganda
8	Zambia	16	Seychelles	24	Liberia	32	Mauritius

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