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Environmental sustainability in Sub-Saharan Africa: Does information and communication technology (ICT) matter?

Mamadou Asngar Thierry¹, Ongo Nkoa Bruno Emmanuel^{2*} and Nchofua Protus Biondeh²

Abstract: This study investigates the effect of information and communication technology (ICT) on environmental sustainability in 38 Sub-Saharan African (SSA) countries over a period 2000–2016. ICT is measured by internet penetration and mobile phone penetration whereas environmental sustainability is measured by CO₂ emissions. The empirical evidence is based on the extended stochastic impact by regression on population, affluence and technology model. As estimation techniques, pooled ordinary least squares (OLS), fixed effect (FE), random effect (RE), panel correlated standard error (PCSE) and feasible generalised least squares (FGLS) are employed. The finding broadly shows that investment in ICT infrastructure enhances environmental sustainability. In addition, the effect of ICT is uniform across different income levels in SSA. As a policy implication, universal ICT access that encourages low pricing and broad coverage of equipment should be considered.

Subjects: Sustainable Development; Economics and Development; Environment & the Developing World; Environmental Economics; Manufacturing Industries; Information Technology

Keywords: CO₂ emissions; ICT; environmental sustainability; Sub-Saharan Africa

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1. Introduction

Sustainability has become a moral and economic imperative since nature, society and businesses are strongly interdependent (Kiron & Unruh, 2018). Subsequently, nations' success is no longer measured in only economic terms but now includes social and environmental terms. Paradoxically, in reality, the world seems to be far from a sustainable place at present. The negative footprints, climate crises, severe loss of biodiversity, pollution, inequality and social tensions, combined with considerable and ongoing unsustainable behaviours continue or have worsened over time (Kopnina, 2020).

Recent progress towards combating the environmental challenges generated by human activities have- not prevented damage to the environment (Leal-Filho et al., 2019a; Sabau, 2020), which has motivated streams of research on environmental issues and the effects of information and communication technology (ICT) as a potentially mitigating element in this digital age (UN (United Nations), 2019b; De Camargo-Fiorini et al., 2019; Corbett, 2018; Gijzen, 2013; WEF (World Economic Forum), 2020a).

ICT is rapidly penetrating contemporary economies. Statistics from the international telecommunication union (ITU, 2019) demonstrate an absolute change of 5.02 billion, 855.07 million, – 301.23 million, 2.87 billion and 5.95 billion in the level of subscription for active mobile broadband subscriptions, fixed broadband subscriptions, fixed-telephone subscriptions, individuals using the internet and mobile cellular telephone subscriptions, respectively between 2005 and 2018.

This study is motivated by three main purposes, which include (i) the enormous ICT penetration in Sub-Saharan Africa (SSA), (ii) growing environmental degradation as a result of carbon dioxide (CO₂) emission and (iii) gaps in prevailing literature. These three explorations are expanded successively as the research unfolds.

Underlying literature on ICT indicates that there is considerable room for further ICT penetration in SSA, compared to some emerging economies (e.g., in Asia and Latin America) and developed nations where ICT penetration has reached saturation level (see, Asongu & Nwachukwu, 2016a; Penard et al., 2012). ICT has been documented as presenting a potential opportunity for policy-makers to address issues of sustainable development, such as environmental degradation through CO₂ emissions (Asongu, 2018; Asongu et al., 2017).

Achieving sustainable development and environmental protection is extremely challenging without three main elements of accountability, transparency and public participation through information flow (Chemutai, 2009). According to the UN Task Force on Environment and Human Settlement, national coordination is the only effective approach for successful environmental governance. Chemutai (2009) asserts that full implementation of Agenda 21 and Multilateral Environmental Agreements in Africa is only possible through effective national and international communication strategies. Subsequently, ICT penetration has considerable potential for enhancing environmental sustainability. CO₂ contributes to environmental degradation; hence, in this study, CO₂ emissions are used to measure environmental sustainability.

Environmental sustainability by means of reducing CO₂ emissions is one of the urgent policy agendas in the post-2015 development era (Asongu et al., 2016). There are three primary reasons for concerns regarding environmental sustainability in SSA. (i) In the last two decades, Africa has experienced a recent phase of growth following several decades of recession, which is due partly to failed Structural Adjustment Programmes (see, Fosu, 2015). As a result, the continent now hosts seven of the ten fastest-growing economies in the world (Asongu & Rangan, 2015). (ii) SSA's post-2015 development era is challenged by an energy crisis. More specifically, only about 5% of the residents in SSA have access to electricity (Shurig, 2015). In addition, the energy consumption in the sub-region is below 17% of the global average. (iii) Most African countries are characterised by energy inefficiency (see, Anyangwe, 2014). For example, Nigeria devotes a substantial proportion

of government resources to subsidising the use of fossil fuels, rather than investing in alternative and renewable energy sources, resulting in the wide use of fuel-powered electricity generators burning subsidised petroleum fuel to compensate for electricity outages and supply shortages (Akan & Akan, 2012). Kifle (2008a) contends that Africa is the continent that will be the most harmfully affected by the adverse effects of global warming. This is congruent with Akan and Akan (2012), who assert that CO₂ emissions account for about three-quarters of world greenhouse gas (GHG) emissions.

The first strand of literature addressing the issue of environmental sustainability through reducing CO₂ emissions is based on the relationship between economic growth and environmental pollution, with emphasis on the environmental Kuznets curve (EKC)¹ hypothesis (Akbostanci et al., 2009; He and Richard, 2010). According to the EKC hypothesis, in the long run, there is an inverted U-shaped relationship between per capita income growth and environmental degradation (see Kaika and Zervas, 2013). The second strand examines energy consumption, environmental pollution and economic growth (Bölük & Mehmet, 2015; Menyah & Wolde-Rufael, 2010; Ozturk & Acaravci, 2010) to assess the interaction between economic growth and energy consumption, while the last reveals these correlations (Esso, 2010).

The major shortcoming of previous literature is the exclusion of a policy variable through which CO₂ emissions can be controlled for environmental sustainability has recently motivated growing research on the relationship between ICT and CO₂ emissions. However, this growing literature has reached a consensus regarding whether ICT reduces, increases or even influences CO₂ emissions.

The remainder of the study is structured as follows. Section 2 present the literature review, Section 3 describes the methodology and data, the empirical results are presented in Section 4 and Section 5 concludes with proposed policy implications and future research directions.

2. Literature review

This section presents a summary of the theoretical and empirical evidence regarding the effects of ICT on environmental sustainability.

2.1. Theoretical assertions regarding ICT and environmental sustainability

The concept of environmental sustainability refers to the ecosystem remaining productive and resilient (resistant) to support human life. The construct relates to the integrity and quality of the ecosystem and the carrying capacity of the natural environment (Brodhag & Taliere, 2006). The theoretical anchoring of technology and sustainability is related to the neoclassical weak sustainability theory and the ecological theory of strong sustainability.

The first neoclassical economics inspiration founded on the notion of weak sustainability was proposed by Hartwick (1977). From the neoclassical mainstream perspective, natural resources (as a source of both inputs and ecosystem services) do not represent an absolute limit to economic growth in the long run. This position is based on two premises: (a) there are almost no limits to scientific or technological progress to increase efficiency in the use of natural resources (eco-efficiency) and (b) capital, labour and natural resources can perfectly substitute one another. Consequently, waste emissions would tend towards zero with the endless increase in the efficient use of natural resources, causing the progressive decoupling of economic growth from the materials/energy base in which the economy operates in a world in which the second law of thermodynamics, the law of entropy, does not apply. In turn, natural ecosystems that are inevitably lost due to human expansion would be easily substituted by artificial capital. Solow (1974) even asserted that the economy could manage without natural resources.

From the perspective of ecological economics, the environment represents an absolute limit to the expansion of the economy, as one of its subsystems. According to this approach, it is not possible to replace essential ecosystem services with capital. Natural resources (natural capital) are

complementary to capital and/or labour. They revise the idea of the perfect substitutable nature of environmental capital to one of complementarity (Goodland & Daly, 1996). This idea is rationally based on the law of entropy, according to which no productive matter or energy change activity (first law of thermodynamics) can occur without an attending irreversible entropic degradation process that generates waste (second law of thermodynamics). It is possible to reduce the amount of waste by increasing eco-efficiency, but it becomes impossible beyond a certain point. Goodland and Daly (1996), the pioneer responsible for incorporating these ideas into the theoretical construct that founded the field of ecological economics, concludes that the total waste unavoidably generated by the extraction, processing and consumption of natural resources in a given period cannot exceed the carrying capacity of the Earth only through the imposition of a limit on growth (zero growth).

Although presenting contradictory perspectives, both theories highlight artificial capital or technology as a means for enhancing sustainability through economic efficiency; therefore, as a presentation of artificial capital, ICT has an essential role in the global pursuit of sustainability.

2.2. A synthesis of empirical research on ICT and environmental sustainability

Considerable research has examined the relationship between ICT and environmental sustainability, in three streams. The first stream of study documents a positive environmental effect of ICT on CO₂ emissions reduction. In this regard, Haseeb et al. (2019) examine the impact of ICT (i.e. internet usage and mobile cellular subscriptions), globalisation, electricity consumption, financial development and economic growth on environmental quality using 1994–2014 panel data of Brazil, Russia, India, China and South Africa (BRICS economies). The results from Westerlund panel co-integration techniques and dynamic seemingly unrelated regression indicate that internet usage and mobile cellular subscriptions (ICT) have a significant adverse impact on CO₂ emissions, implying that ICT positively contributes to environmental quality. In the same perspective, Ekwueme et al. (2021) worked on the case of South Africa. They found that, in the long run, there is a significant positive correlation between renewable energy, economic growth, financial development and carbon emission. Godil et al. (2020) examine the effect of financial development, ICT and institutional quality on CO₂ emissions in Pakistan using the quantile autoregressive distributed lag model, with data obtained for the period from 1995 to 2018. Findings show that financial development and ICT reduce CO₂ emissions irrespective of whether the emissions level is high or low in the country, implying that if financial enhancement and ICT increase, emissions diminish.

Murshed (2020) uses co-integration and heterogeneous causal analysis to investigate the non-linear impacts of ICT-trade (i.e. Interactive modelling) on the prospects of renewable energy transition, improving energy use efficiencies, enhancing access to cleaner cooking fuels and mitigating carbon dioxide emissions across selected South Asian economies of Bangladesh, India, Pakistan, Sri Lanka, Nepal and the Maldives. The results from the econometric analyses reveal that ICT-trade directly increases renewable energy consumption, enhances renewable energy shares, reduces the intensity of energy use, facilitates the adoption of cleaner cooking fuels and reduces CO₂ emissions. These results have been also found by Adewale Alola et al. (2021)

Zhang and Liu (2015) consider regional differences in China to investigate the impact of ICT industry on CO₂ emissions at national and regional levels using the stochastic impact by regression on population, affluence and technology (STIRPAT) model and provincial panel data across the period 2000–2010. The results demonstrate that the ICT industry contributes to reducing China's CO₂ emissions and the impact of the ICT industry on CO₂ emissions in the central region is higher than that in the eastern region, while that in the western region is insignificant. Malmodin and Bergmark (2015) use descriptive analysis to explore the potential future effects of ICT solutions on GHG emissions in 2030 based on available data on real GHG emissions reduction from different ICT solutions. The results indicate a total GHG emissions reduction potential from the ICT solutions of

about 8 Gtonnes CO₂e or 12% of global GHG emissions in 2030 in a potential high reduction scenario and 4 Gtonnes CO₂e in 2030 or 6% in a potential medium reduction scenario.

Khan et al. (2022b), evaluate the effect of CO₂ emissions, renewable energy sources, ICT, governance and GDP in Morocco using a time-series dataset over the period 1985–2020 and a dynamic autoregressive distributed lag (ARDL) model. The findings suggest that renewable energy sources (i.e. solar, wind, hydroelectric), ICT and effective governance are the key indicators for reducing carbon emissions. Khan et al. (2022c) further investigated the correlations between private investment in ICT, CO₂ emissions, renewable energy, political risk and economic growth over the period of 1985–2020 in Morocco, finding significant evidence of the importance of private partnership in ICT for decarbonisation and widespread renewable energy adoption.

Recent studies also highlight the positive environmental effect of ICT in the transport sector. For instance, Chatti and Majeed (2022) investigates how ICT interacts with road freight transport to affect environmental quality in terms of CO₂ emissions reduction. Using panel data from 2002 to 2014 in 43 countries, the author's findings from two-step generalised method of moments (GMM) techniques suggest that ICTs can decrease the negative impacts of road freight transport on environmental sustainability. Furthermore, Chatti and Majeed (2022) investigate the links between ICT, passenger transportation and environmental sustainability. Using a panel dataset for 46 countries from 1998 to 2016, the results from two-step GMM show that the association between ICTs and passenger transportation activity can positively affect environmental sustainability in terms of CO₂ emissions reduction.

The second stream of literature demonstrates a positive correlation between ICT and CO₂ emissions. To this effect, Lee and Brahmashrene (2014) use panel data constructed from 1991 to 2009 for nine members of the Association of Southeast Asian Nations, examining the relationships among ICT, CO₂ emissions and economic growth. Co-integration techniques are used to examine the long-run equilibrium and short-run relationship and the results reveal a long-run equilibrium relationship among the variables. Among these relationships, ICT has significant to highly significant positive effects on both economic growth and CO₂ emissions. Asongu (2018) investigates how ICT complements globalisation to influence CO₂ emissions in 44 SSA countries over the period 2000–2012. ICT is measured by internet and mobile phone penetration, whereas globalisation is designated in terms of trade and financial openness. With empirical evidence based on the GMM, the author finds that internet and mobile phone penetration exert a significant positive impact on CO₂ emissions reduction. The findings broadly demonstrate that ICT can dampen the potentially negative effects of globalisation on environmental degradation, such as CO₂ emissions, through the interactive specification of ICT indicators and the variables measures of globalisation.

Zhou et al. (2018) analyse the major drivers behind changes in China's energy intensity, with emphasis on ICT and production structure, using a three-tier structural decomposition analysis. The main results indicate that (a) production structure exerts a rising negative effect on China's energy intensity change from 2002 to 2012, (b) ICT contributes to a 4.54% increment in energy intensity, however ICT input substitution was conducive to reducing energy use in production and (c) the ICT effects were more significant in service and technology-intensive sectors.

Avom et al. (2020) use the STIRPAT model to estimate both the effect and transmission channels of ICT on CO₂ emissions, examining panel data in 21 SSA countries from 1996 to 2014. The authors employ estimation techniques, such as feasible generalised least squares (FGLS) and panel correlated standard error (PCSE), finding that ICT use—measured by mobile phone and internet penetrations—significantly fuels CO₂ emissions. The authors further conduct mediation analysis, and the results show that ICT not only has a direct positive total effect on CO₂ emissions but also an indirect positive effect through lowering energy consumption and raising financial development, and an indirect negative effect through trade openness.

The final stream of literature finds no significant relationship between ICT and environmental degradation through CO₂ emissions. For example, Asongu et al. (2017), examine whether increasing ICT penetration in SSA contributes to environmental sustainability by decreasing CO₂ emissions, basing the empirical evidence on the GMM with a sample of 44 countries for the period 2000–2012. The authors establish two main findings. First, based on non-interactive regressions, ICT (mobile phone and internet penetration) does not significantly affect CO₂ emissions. Second, interactive regressions indicate that increasing ICT has a positive net effect on CO₂ emissions per capita, whereas increasing mobile phone penetration alone has a net negative effect on CO₂ emissions from liquid fuel consumption. Their findings imply that the effect of ICT on CO₂ emission is highly conditional.

Amri et al. (2019) examine the correlations between CO₂ emissions, total factor productivity as a measure of income and ICT in Tunisia from 1975 to 2014, demonstrating an insignificant impact of ICT on CO₂ emissions as a measure of pollution and no impact of ICT on sustainable development based on an ARDL approach.

Based on this previous literature, there is evidently no global consensus on the environmental effect of ICT penetration through CO₂ emissions. Existing studies have also not considered income differences when investigating the relationship between ICT and CO₂ emissions. This is an essential consideration, as several studies point out that the ICT effect is subjective in terms of income levels. To empirically examine this assertion, Shiu and Lam (2008) investigate the causal relationship between ICT development and economic growth, finding a bidirectional relationship between ICT development and economic growth for European and high-income countries. For countries in developing and emerging regions and lower-income groups, the relationship is generally unidirectional, from real GDP to ICT development.

Based on these conflicting findings, it is essential to conduct further new research on the effect of ICT penetration on environmental quality. The positioning of this study departs from recent literature on the relationship between ICT and environmental sustainability by investigating whether this relationship is uniform across income levels, as the level of growth and development in SSA is not uniform in terms of per capita income. The study period also extends to 2016, given that previous studies in the context of SSA have been limited to 2014.

3. Methodology and data

3.1. Methodology

Among several models that are used to assess the impact of anthropogenic activities on the environment is the IPAT equation, developed by Ehrlich and Holdren (1971). Following these authors, environmental impact (I) is a linear function of population size (P), the level of affluence (A) and technology (T) i.e. $I = P \times A \times T$. As this model and its variant do not allow for including the non-proportional effect of the driving forces (York et al., 2003), the STIRPAT model proposed by Dietz and Rosa (1994) allows for more flexibility than the other variants. The basic STIRPAT model is written as follows:

$$I_{it} = \alpha P_{it}^{\beta} A_{it}^{\gamma} T_{it}^{\delta} \varepsilon_{it} \quad (1)$$

where the subscripts i and t stand for country and time, respectively; α is a constant; β , γ and δ are the respective parameters associated with P, A and T and ε is the error term. To facilitate empirical estimation and hypothesis testing, this model is often converted into a logarithmic form:

$$\ln I_{it} = \theta + \beta \ln P_{it} + \gamma \ln A_{it} + \delta \ln T_{it} + \ln \varepsilon_{it} \quad (2)$$

where $\ln()$ is the natural log and θ represents $\ln \alpha$.

CO₂ emissions in metric tonne is our dependent variable, rationalised by the fact that emissions cause environmental degradation and air pollution and is largely employed in underlying literature as a measure of environmental degradation (Asongu et al., 2017; Asongu, 2018; Avom et al., 2020).

Consistent with recent ICT literature, internet and mobile phone penetration are used as proxies to measure ICT (Penard et al., 2012; Asongu, 2014; Tony & Kwan, 2015; Tchamyu, 2016), and per capita GDP is used to measure economic growth. Additional variables are included in the model to account for omitted variable bias, including population growth, trade openness (as a percentage of GDP) and energy consumption (see Appendix 2 for variable definitions).

Equation (2) is reformulated to include additional variables as follows:

$$\ln CO_{2it} = \alpha_0 + \alpha_1 \ln ICT_{it} + \beta_1 \ln GDP_{pcit} + \beta_2 \ln GDP_{pcit}^2 + \beta_3 \ln Pop_{it} + \beta_4 trade_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (3)$$

where CO_{2it} is the amount of carbon emissions in country i at time t ; ICT_{it} is the proxy of ICT, measured by internet use (in percentage of the population), mobile phone penetration (in percentage of 100 people); GDP_{pcit} is per capita GDP in country i at period t ; and GDP_{pcit}^2 is the square of per capita GDP, to test the EKC hypothesis. Pop_{it} is the total population measured in the number of inhabitants and $trade$ represents the total import and export of goods and services measured as a percentage of GDP. α_0 is a constant term, β_i ($i = 1, 2, 4$) and α_1 is interpreted as CO₂ emissions elasticities with respect to the independent variables. μ_i is the individual specific effect, φ_t is the fixed time effect and ε_{it} is the stochastic error term.

We also assume that the effect of ICT is non-linear, as changes in ICT penetration, may have varying effects on environmental quality. To this effect, we square the term of ICT in equation (4) to test for non-linearity (see, Añón Higón et al., 2017 for theoretical arguments on this specification). Therefore, the equation to be estimated is as follows:

$$\ln CO_{2it} = \alpha_0 + \alpha_1 \ln ICT_{it} + \alpha_2 \ln ICT_{it}^2 + \beta_1 \ln GDP_{pcit} + \beta_2 \ln GDP_{pcit}^2 + \beta_3 \ln Pop_{it} + \beta_4 trade_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (4)$$

where $\ln ICT_{it}^2$ represents the square term of ICT. Equation (4) enables us to investigate the varying effect of ICT on environmental sustainability depending on the signs that α_i ($i = 1, 2$) takes. For instance, if α_1 and α_2 are positive and negative, respectively, the implication is that a high level of ICT is accompanied by a decline in CO₂ emissions, and if both the coefficients have positive signs it implies that a higher level of ICT is associated with higher-level CO₂ emission in SSA.

From equation (4), α_1 is expected to be negative, demonstrating a negative effect of ICT on carbon emissions. Based on the environmental EKC hypothesis, β_1 is expected to be positive and a negative sign is expected for β_2 , implying that environmental quality initially worsens with economic growth until reaching a threshold income level at which increased income improves environmental quality. β_3 is expected to be positive, implying that growth results in increased CO₂ emissions, and β_4 is expected to be negative, signifying that trade openness reduces CO₂ through the importation of energy-efficient material.

3.2. Data and descriptive analysis

This study employs data from the World Bank (2022) covering the period from 2000 to 2016 for a sample of 38 SSA countries. The geographical and temporal scopes of the study are driven by data availability constraints on the variables used. Appendix 1 presents the list of these countries.

Figures 1 and Figure 2 provide a visual illustration of the annual average trends of key variables. Figure 1 demonstrates that the average rate of internet penetration rose from 0.914% in 2000 to 21.1% in 2016, with Seychelles recording 56.52% as the highest in 2016. South Africa and Mauritius

Figure 1. The average annual trend of ICT penetration is SSA (2000–2016).

Source: Authors' calculations.

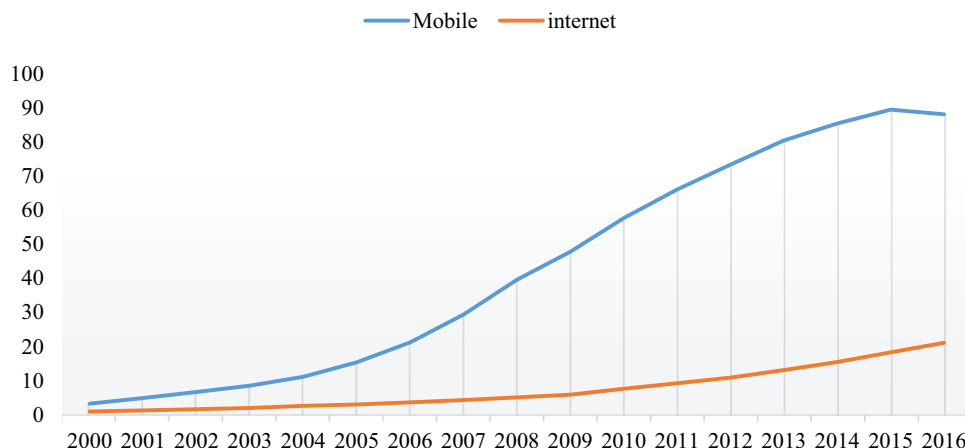
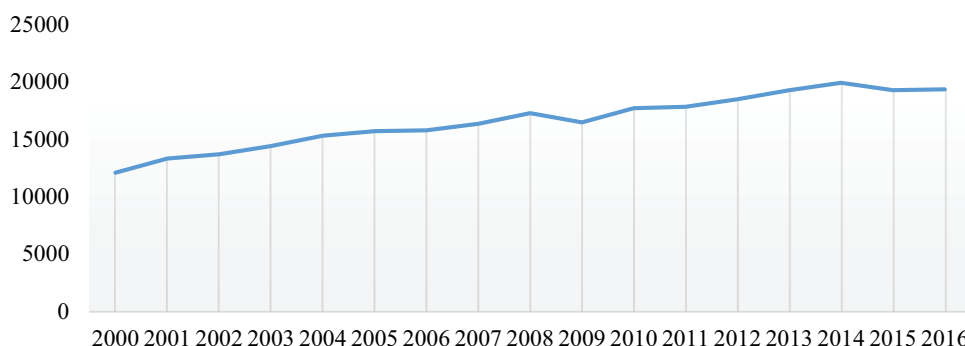


Figure 2. Average annual trend of CO₂ emissions in SSA (2000–20016).

Source: Authors' calculations.



are some of the prominent countries presenting high penetration. The lowest record is from the Democratic Republic of Congo in 2000 at 0.005902%. Average mobile phone subscribers rose from 3.1989 per 100 people in 2000 to 88.1091 in 2016.

The maximum number of subscribers in the 38 selected SSA countries amounts to 163.8752, which was recorded by Botswana in 2016. Other countries that recorded high subscription rates include South Africa and Seychelles, amongst others, while the minimum number of subscribers per every 100 people is 0.01, recorded by Comoros in 2000.

Figure 2 presents the annual average trend of CO₂ emissions released into the atmosphere by SSA countries. From 2000 to 2016, average emissions rose from 12070.52632kt to 19349.73684kt. Maximum emissions of 447980kt in 2014 were generated, followed by Nigeria and Angola as main emitters.

The descriptive summary statistics in Table 1 suggest fluctuations in our independent variables of interest. The mean scores of ICT are 42.834 and 7.384 for mobile phone and internet penetration. Comparatively, mobile phone penetration appears to be considerably high.

The correlation matrix (Table 2) confirms no threat of multicollinearity. The variance inflation factor (VIF; Table 3) test also reveals no evidence of multicollinearity among regressors as all VIFs are less than 10 and tolerance factors are greater than 0.1.

Table 1. Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CO2	646	16593.762	63936.777	100	447980
Internet	646	7.384	10.808	0.006	56.515
Mobile	646	42.834	40.713	0.01	163.875
GDPpc	646	2275.356	3328.022	113.567	22942.61
Trade	646	70.714	34.762	20.723	225.023
Pop	646	17365258	26776246	81131	1.860e+08

Note: All variables in log.

Source: Authors

Table 2. Matrix of correlation

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) CO2	1.000					
(2) Internet	0.258	1.000				
(3) Mobile	0.211	0.797	1.000			
(4) GDPpc	0.195	0.592	0.476	1.000		
(5) Trade	-0.106	0.387	0.322	0.594	1.000	
(6) Population	0.401	0.007	-0.009	-0.134	-0.303	1.000

Note: All variables in log.

Source: Authors

Table 3. Variance inflation factor (VIF) test for multicollinearity

	VIF	1/VIF		VIF	1/VIF
GDPpc	2.891	0.346	GDPpc	2.4	0.417
Internet	2.013	0.497	Mobile	1.661	0.602
Trade	1.821	0.549	Trade	1.829	0.547
Population	1.412	0.708	Population	1.501	0.666
Mean VIF	2.034	.	Mean VIF	1.848	.

Note: All variables in log.

Source: Authors

4. Empirical result and discussion

This section presents and discusses the results of the effect of ICT on environmental sustainability.

The baseline result used pooled Ordinary Least Square (OLS), fixed effect (FE) and random effect (RE) estimators, which is presented in two models according to the different proxies of ICT. In the first model, ICT is captured by mobile phone use, whereas ICT is captured by internet penetration in the second model. As seen in Appendix 3, the results are presented in both linear and non-linear specifications.

The results of the pooled estimator indicate the quality of the model, as seen from the coefficient of determination (R-squared), which is 0.895 for the mobile phone model and 0.881 for the internet model.

Regarding the fixed and random effects results, the Hausman specification test is employed to choose the best from the two, and as a result, the FE is retained, as all probabilities (p-values) permit us to reject the null hypothesis of no symmetric difference (i.e. p-value less than a 5%

significance level). Wald and Wooldridge tests are employed to examine issues concerning heteroscedasticity and autocorrelation, respectively. The results of these tests indicate the presence of group-wise heteroscedasticity and autocorrelation, rendering the FE estimator inconsistent and biased. To consider this econometric problem, we employ PCSE and FGLS estimators, which Reed and Ye (2011) assert are appropriate for considering the econometric problem detected. The authors also advocate that while the FGLS estimator is efficient, PCSE is accurate in hypothesis tests; thus, we use the two estimators to assess the robustness of our findings.

Tables 4 and 5 respectively present the results of the FGLS and PCSE estimators for both linear and non-linear specifications. The PCSE estimator (Table 4) reveals the high quality of the model, as seen from the coefficient of determination (R-squared), which is above 80%. In both estimators, the signs of the coefficient remain the same, demonstrating the reliability of our results.

From the linear specification, the ICT proxies (mobile phone and internet) have a statistically significant negative effect on CO₂ emissions, indicating that a 1% increase in the rate of mobile phone and internet penetration reduces the rate of CO₂ emissions by 0.18% and 0.136%, respectively. This implies that ICT has a positive influence on environmental sustainability, which could be due to energy efficiency resulting from ICT use. This confirms the findings of Haseeb et al. (2019), who obtained results indicating that ICT significantly reduces CO₂ emissions in BRICs countries. Contrarily, Avom et al. (2020) find that a 1% increase in the rate of internet and mobile phone penetration increases CO₂ emissions by 0.0358% and 0.0344%, respectively. This result can be

Table 4. FGLS regression of ICT on CO2

VARIABLES	Linear specification		Nonlinear specification	
	CO2	CO2	CO2	CO2
Mobile	-0.176*** (0.00464)		-0.125*** (0.00491)	
Mobile squared			-0.0185*** (0.00131)	
Internet		-0.131*** (0.00709)		-0.138*** (0.00746)
Internet Squared				0.00595*** (0.00198)
GDPpc	2.090*** (0.0522)	1.644*** (0.0436)	2.105*** (0.0473)	1.702*** (0.0429)
GDPpc squared	-0.0593*** (0.00341)	-0.0317*** (0.00268)	-0.0581*** (0.00308)	-0.0361*** (0.00267)
Pop	1.057*** (0.00282)	1.023*** (0.00301)	1.055*** (0.00269)	1.023*** (0.00307)
Trade openness	0.608*** (0.0146)	0.539*** (0.0130)	0.584*** (0.0180)	0.549*** (0.0151)
Constant	-22.48*** (0.161)	-20.30*** (0.176)	-22.45*** (0.146)	-20.55*** (0.185)
Observations	646	646	646	646
countries	38	38	38	38
chi2	192760***	173271***	264322***	170937***
Net effect of ICT			-0.91743	-0.0941

Notes: * p < 0.1; ** p < 0.05; *** p < 0.01; Standard errors in parentheses; na signifies not applicable because at least one of the values needed in the computation is insignificant; bold value is net effect; all variables in log.

Source: Authors

Table 5. PCSE regression of ICT on CO₂

	Linear specification		Nonlinear specification	
VARIABLES	CO ₂	CO ₂	CO ₂	CO ₂
Mobile	−0.180*** (0.0192)		−0.130*** (0.0243)	
Mobile squared			−0.0182*** (0.00634)	
Internet		−0.136*** (0.0405)		−0.141*** (0.0452)
Internet squared				0.00463 (0.0166)
GDPpc	2.110*** (0.181)	1.676*** (0.190)	2.129*** (0.174)	1.730*** (0.210)
GDPpc squared	−0.0606*** (0.0128)	−0.0334*** (0.0127)	−0.0595*** (0.0120)	−0.0374*** (0.0144)
Population	1.057*** (0.0142)	1.023*** (0.0126)	1.056*** (0.0121)	1.023*** (0.0123)
Trade openness	0.618*** (0.0591)	0.538*** (0.0568)	0.589*** (0.0495)	0.543*** (0.0517)
Constant	−22.59*** (0.584)	−20.43*** (0.721)	−22.56*** (0.533)	−20.64*** (0.694)
Observations	646	646	646	646
R-squared	0.895	0.881	0.897	0.881
Countries	38	38	38	38
chi2	27937***	29911***	36105***	31032***
Net effect of ICT			−0.9096	na

Notes: * p < 0.1; ** p < 0.05; *** p < 0.01; Standard errors in parentheses; na signifies not applicable because at least one of the values needed in the computation is insignificant; bold value is net effect; all variables in log.

Source: Authors

partly explained by the fact that ICT reduces the rate of travelling, and previous literature documents the importance of ICT in dampening CO₂ emissions through networking possibilities, which decrease the cost/traffic per minute associated with economic operations (Esselaar et al., 2007; Gille et al., 2002; Gutierrez et al., 2009).

Regarding the non-linear specification, the coefficients of the proxies of ICT appear to be negative, implying the existence of a non-linear (inverted U-shaped) relationship between ICT and CO₂ emissions. This is consistent with the work of Asongu et al. (2017), who establish a non-linear relationship between ICT and CO₂ emissions in 44 SSA countries. Similarly, Añón Higón et al. (2017) detect an inverted-U-shaped curve between ICT and CO₂ emissions in a sample of 142 countries.

The net effect is computed to examine the overall impact of ICT penetration on CO₂ emissions. For instance, the net effect from internet penetration in Table 4 is −0.0941 ([0.00595 × 7.384] + [−0.138]). In the computation, the mean value of internet penetration is 7.384, the unconditional effect of mobile phone penetration is −0.138, while the conditional effect from internet penetration is 0.00595. The net effect of mobile phone penetration is −0.91743. The net negative effect implies that further development in ICT infrastructure can be advanced for environmental sustainability, is consistent with the findings of Asongu et al. (2017).

Table 6. Sensitivity of non-interactive regression for low income countries

Estimation technique = FGLS			Estimation technique = PCSE		
VARIABLES	CO2	CO2	VARIABLES	CO2	CO2
Mobile	−0.104*** (0.00140)		Mobile	−0.107*** (0.0154)	
Internet		−0.106*** (0.00436)	Internet		−0.109*** (0.0280)
GDPpc	1.367*** (0.0628)	1.293*** (0.0991)	GDPpc	0.732*** (0.0119)	0.692*** (0.0131)
GDPpc squared	−0.0221*** (0.00524)	−0.0210** (0.00830)	GDPpc squared	1.407** (0.709)	1.246 (0.783)
Population	0.730*** (0.00345)	0.689*** (0.00474)	Population	−0.0236 (0.0561)	−0.0158 (0.0627)
Trade openness	0.720*** (0.00815)	0.714*** (0.0132)	Trade openness	0.728*** (0.0578)	0.732*** (0.0560)
Constant	−14.88*** (0.192)	−14.00*** (0.311)	Constant	−15.12*** (2.218)	−14.03*** (2.476)
Observations	289	289	Observations	289	289
Countries	17	17	R-squared	0.837	0.827
			Countries	17	17
chi2	84424***	33482***	chi2	4861***	7464***

Notes: * p < 0.1; ** p < 0.05; *** p < 0.01; Standard errors in parentheses; na: signifies not applicable because at least one of the values needed in the computation is insignificant; bold value is net effect; all variables in log.

Source: Authors

Table 7. Sensitivity of non-interactive regression for lower middle-income countries

Estimation technique = FGLS			Estimation technique = PCSE		
VARIABLES	CO2	CO2	VARIABLES	CO2	CO2
Mobile	−0.0809*** (0.00434)		Mobile	−0.0804*** (0.0137)	
Internet		−0.0125*** (0.00319)	Internet		−0.0121 (0.0202)
GDPpc	0.826*** (0.0691)	0.0316 (0.0816)	GDPpc	1.073*** (0.00908)	1.052*** (0.00868)
GDPpc squared	−0.0178*** (0.00473)	0.0292*** (0.00560)	GDPpc squared	0.843* (0.495)	−0.00796 (0.615)
Population	1.074*** (0.00156)	1.053*** (0.00171)	Population	−0.0190 (0.0341)	0.0317 (0.0426)
Trade openness	0.860*** (0.00790)	0.833*** (0.00962)	Trade openness	0.866*** (0.0465)	0.840*** (0.0538)
Constant	−17.15*** (0.266)	−13.66*** (0.310)	Constant	−17.23*** (1.932)	−13.53*** (2.366)
Observations	238	238	Observations	238	238
Countries	14	14	R-squared	0.950	0.947
			Countries	14	14
chi2	888680***	490255***	chi2	18462***	20359***

Notes: * p < 0.1; ** p < 0.05; *** p < 0.01; Standard errors in parentheses; all variables in log.

Source: Authors

Table 8. Sensitivity of non-interactive regression for upper middle-income countries

Estimation technique = FGLS			Estimation technique = PCSE		
VARIABLES	CO2	CO2	VARIABLES	CO2	CO2
<i>Mobile</i>	−0.423*** (0.0311)		<i>Mobile</i>	−0.435*** (0.0553)	
<i>Internet</i>		−0.135*** (0.0220)	<i>Internet</i>		−0.156*** (0.0445)
<i>GDPpc</i>	5.835*** (0.790)	−0.629 (0.520)	<i>GDPpc</i>	1.270*** (0.0390)	1.209*** (0.0463)
<i>GDPpc squared</i>	−0.268*** (0.0447)	0.0850*** (0.0302)	<i>GDPpc squared</i>	6.016*** (2.299)	−1.311 (2.348)
<i>Population</i>	1.255*** (0.0145)	1.221*** (0.0161)	<i>Population</i>	−0.272** (0.128)	0.128 (0.133)
<i>Trade openness</i>	0.558*** (0.0777)	0.537*** (0.0696)	<i>Trade openness</i>	0.637*** (0.184)	0.488** (0.206)
<i>Constant</i>	−40.62*** (3.522)	−12.04*** (2.301)	<i>Constant</i>	−42.45*** (10.06)	−8.870 (10.42)
<i>Observations</i>	119	119	<i>Observations</i>	119	119
<i>Countries</i>	7	7	<i>R-squared</i>	0.946	0.934
			<i>Countries</i>	7	7
<i>chi2</i>	46889***	11657***	<i>chi2</i>	18462***	20359***

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; Standard errors in parentheses; all variables in log.

Source: Authors

Regarding other variables, the effect of economic growth is consistent with the EKC hypothesis, implying that further growth in per capita income will reduce CO₂ emissions. The results also demonstrate that population has a significant influence on CO₂ emissions. The elasticities of the population appear positive and highly significant, which could be related to the constant expansion of population-scale accelerating the consumption of energy and living resources, thus producing greater environmental pressure. This is consistent with Bargaoui et al. (2014) and Li et al. (2015).

Finally, an increase in the trade openness is associated with reduction in CO₂ emissions. This is explained by the fact that developing countries such as those in SSA, which are primarily endowed with natural resources and labour, will produce and export fewer polluting goods. Meanwhile, developed countries specialise in the production of capital-intensive goods that are high-polluting. This is consistent with the findings of Saboori et al. (2016) and Avom et al. (2020) in Malaysia and SSA, respectively.

A cross-income analysis is conducted to examine the sensitivity of our results. Tables 6 and 7 summarise the robustness results. This is because the level of growth and development in SSA countries is not uniform, resulting in differences in growth of per capita income. This is also to investigate whether the ICT effect on CO₂ emissions in SSA is uniform across income levels. Table 8 presents the results of this sensitivity analysis for low-, lower-middle and upper-middle-income countries, respectively.

The results show that ICT reduces CO₂ emissions across all income levels. Notably, reductions in CO₂ emissions are higher in upper-middle-income countries, which are also countries with high ICT penetration, implying that increasing ICT penetration enhances environmental sustainability.

5. Conclusion and policy implications

The study examined the effect of ICT on environmental sustainability measured through CO₂ emissions in 38 SSA countries from 2000 to 2014, measured by mobile phone and internet penetration. The empirical evidence is based on the STIRPAT model. Three notable findings can be established. First, from the non-linear specification, we conclude that increasing ICT (mobile phone and internet) penetration significantly increases CO₂ emissions. Second, from the linear specification, the effect of ICT on CO₂ emissions is negative. Also, increasing ICT has a net negative effect on CO₂ emissions. The net negative effect implies that further penetration in ICT will reduce CO₂ emissions. Third, cross-income analysis revealed that the effect of ICT is uniform across income levels; thus, increasing ICT penetration and use will dampen the environmental effects of CO₂ emission in SSA.

The primary policy implication of the findings is that investing in ICT infrastructure can enhance environmental sustainability through the reduction of CO₂ emissions. Policymakers can leverage the established findings in the post-2015 development era by addressing issues related to ICT penetration, such as affordability and lack of infrastructure. Also, as universal access encourages low pricing. National schemes such as the Rwanda Information Technology Authority (RITA) should be encouraged in other African countries. RITA consolidates and coordinates the pricing and distribution of the nation's ICT resources (Chemutai, 2009).

Two limitations to this study are worth highlighting. First, one methodological handicap is the omission of the increase in CO₂ emissions related to regional deforestation in SSA. A decrease in CO₂ absorption capacity caused by rainforest destruction could be computed and integrated with the data on CO₂ emissions from fossil fuel. Regrettably, the variables employed in this study were directly obtained from World Development Indicators, and no further investigation could be conducted due to the absence of data.

Second, the findings from the cross-income analysis on the ICT effect are specific to the SSA region. Further study could extend this investigation to the entire African continent, which would yield findings that are relevant for more targeted policy implications.

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Note

1. According to the EKC hypothesis, in the long run, there is an inverted U-shaped relationship between per capita income growth and environmental degradation (see Kaika and Zervas, 2013).

References

- Adewale Alola, A., Ozturk, I., & Bekun, F. V. (2021). Is clean energy prosperity and technological innovation rapidly mitigating sustainable energy-development deficit in selected sub-Saharan Africa? A myth or reality. *Energy Policy*, 158, 112520. <https://doi.org/10.1016/j.enpol.2021.112520>
- Akbostanci, E., Turut-Asi, S., & Tunc, G. I. (2009). The relationship between income and environment in Turkey: Is there an environmental Kuznets curve? *Energy Policy*, 37(3), 861–867. <https://doi.org/10.1016/j.enpol.2008.09.088>
- Akpan, G. E., & Akpan, U. F. (2012). Electricity consumption, carbon emissions and economic growth in Nigeria. *Int J Energy Econ Policy*, 2(4), 292–306.
- Amri, F., Zaied, Y. B., & Lahouel, B. B. (2019). ICT, total factor productivity, and carbon dioxide emissions in Tunisia. *Technological Forecasting and Social Change*, 146, 212–217. <https://doi.org/10.1016/j.techfore.2019.05.028>
- Añón Higón, D., Gholami, R., & Shirazi, R. (2017). ICT and environmental sustainability: A global perspective. *Telematics and Informatics*, 34(4), 85–95. <https://doi.org/10.1016/j.tele.2017.01.001>

- Anyangwe, E. (2014). *Without energy could Africa's growth run out of steam?* The Guardian. Retrieved: 08 September 2015 from <http://www.theguardian.com/global-development-professionalsnetwork/2014/nov/24/energy-infrastructure-clean-cookstoves-africa>
- Asongu, S. A. (2014). Globalization, (fighting) corruption and development: How are these phenomena linearly and nonlinearly related in wealth effect? *Journal of Economic Studies*, 41(3), 346–369. <https://doi.org/10.1108/JES-04-2012-0048>
- Asongu, S. A. (2018). ICT, openness and CO 2 emissions in Africa. *Environmental Science and Pollution Research*, 25(10), 9351–9359. <https://doi.org/10.1007/s11356-018-1239-4>
- Asongu, S. A., El Montasser, G., & Toumi, H. (2016). Testing the relationships between energy consumption, CO2 emissions, and economic growth in 24 African countries: A panel ARDL approach. *Environmental Science and Pollution Research*, 23(7), 6563–6573. <https://doi.org/10.1007/s11356-015-5883-7>
- Asongu, S. A., Le Roux, S., & Biekpe, N. (2017). Enhancing ICT for environmental sustainability in Sub-Saharan Africa. *Technological Forecasting and Social Change*, 118, 44–54. <https://doi.org/10.1016/j.techfore.2017.09.022>
- Asongu, S. A., & Nwachukwu, J. C. (2016a). The mobile phone in the diffusion of knowledge for institutional quality in Sub Saharan Africa. *World Development*, 86 (October), 133–147. <https://doi.org/10.1016/j.worlddev.2016.05.012>
- Asongu, S. A., & Rangan, G. (2015). Trust and quality of growth. *Bulletin of Economic*, 36(3), 1854–1867.
- Avom, D., Nkengfack, H., Fotio, H. K., & Totouom, A. (2020). ICT and environmental quality in Sub-Saharan Africa: Effects and transmission channels. *Technological Forecasting and Social Change*, 155, 120028. <https://doi.org/10.1016/j.techfore.2020.120028>
- Bargaoui, S. A., Liouane, N., & Nouri, F. Z. (2014). Environmental impact determinants: An empirical analysis based on the STIRPAT model. *Procedia-Social and Behavioral Sciences*, 109, 449–458. <https://doi.org/10.1016/j.sbspro.2013.12.489>
- Bölük, G., & Mehmet, M. (2015). The renewable energy, growth and environmental Kuznets curve in Turkey: An ARDL approach. *Renewable and Sustainable Energy Reviews*, 52, 587–595. <https://doi.org/10.1016/j.rser.2015.07.138>
- Brodhag, C., & Talieri, S. (2006). Sustainable development strategies: Tools for policy coherence. *Natural Resources Forum*, 30(2), 136–145. <https://doi.org/10.1111/j.1477-8947.2006.00166.x>
- Chatti, W., & Majeed, M. T. (2022). Investigating the links between ICTs, passenger transportation, and environmental sustainability. *Environmental Science and Pollution Research*, 29(18), 26564–26574. <https://doi.org/10.1007/s11356-021-17834-3>
- Chemutai, B. (2009). *Achieving effective national environmental governance in Africa, ISS today*. Retrieved 04 Jul 2017. from <https://issafrica.org/iss-today/achieving-effective-national-environmental-governance-in-africa>
- Corbett, C. J. (2018). How sustainable is big data? *Production and Operations Management*, 27(9), 1685e1695. <https://doi.org/10.1111/poms.12837>
- De Camargo-Fiorini, P., Chiappetta Jabbour, C., Lopes de Sousa Jabbour, A., Oliveira Stefanelli, N., & Fernando, Y. (2019). Interplay between information systems and environmental management in ISO 14001-certified companies: Implications for future research on big data. *Management Decision*, 57(8), 1883e1901. <https://doi.org/10.1108/MD-07-2018-0739>
- Dietz, T., & Rosa, E. A. (1994). Rethinking the environmental impacts of population, affluence and technology. *Human Ecology Review*, 1, 277–300.
- Ehrlich, P. R., & Holdren, J. P. (1971). Impact of Population Growth. *Science*, 171(3977), 1212–1217. <https://doi.org/10.1126/science.171.3977.12>
- Ekwueme, D. C., Zoaka, J. D., & Alola, A. A. (2021). Carbon emission effect of renewable energy utilization, fiscal development, and foreign direct investment in South Africa. *Environmental Science and Pollution Research*, 28(31), 41821–41833. <https://doi.org/10.1007/s11356-021-13510-8>
- Esselaar, B., Gilwald, A., & Stork, C. (2007). Towards an Africa e-index: Telecommunications sector performance in 16 African countries. *Research ICT Africa*, 72. <http://hdl.handle.net/10625/41622>
- Esso, L. J. (2010). Threshold cointegration and causality relationship between energy use and growth in seven African countries. *Energy Economics*, 32(6), 1383–1391. <https://doi.org/10.1016/j.eneco.2010.08.003>
- Fosu, A. K. (2015). Growth, inequality and poverty in Sub-Saharan Africa: Recent progress in a global context. *Oxford Development Studies*, 43(1), 44–59. <https://doi.org/10.1080/13600818.2014.964195>
- Gijzen, H. (2013). Development: Big data for a sustainable future. *Nature*, 502(38), 10.1038/50203 8d. <https://doi.org/10.1038/502038d>
- Gille, L., Noumba Um, P., Rudel, C., & Simon, L., eds. (2002). *A model for calculating inter connection costs in telecommunications*. The World Bank. Retrieved: 27 November 2014 from <http://www.ppiaf.org/sites/ppiaf.org/files/publication/WB%20-%20Model%20Calculating%20Interconnection%20Costs%20Telecoms%202004.pdf>
- Godil, D. I., Sharif, A., Agha, H., & Jermsittiparsert, K. (2020). The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: New insights from QARDL approach. *Environ Sci Pollut Res*, 1.
- Goodland, R., & Daly, H. (1996). Environmental Sustainability: Universal and Non-Negotiable. *Ecological Applications*, 6(4), 1002–1017. <https://doi.org/10.2307/2269583>
- Gutierrez, L. H., Lee, S., & Virto, L. R. (2009). *Market concentration and performance in mobile markets in Africa and Latin America*. OECD Development Center (mimeo).
- Hartwick, J. M. (1977). Intergenerational equity and the investing of rents from exhaustible resources. *American Economic Review*, 67, 972–974.
- Haseeb, A., Xia, E., Saud, S., Ahmad, A., & Khurshid, H. (2019). Does information and communication technologies improve environmental quality in the era of globalization? An empirical analysis. *Environmental Science and Pollution Research*, 26(9), 8594–8608. <https://doi.org/10.1007/s11356-019-04296-x>
- He, J., & Richard, P. (2010). Environmental Kuznets curve for CO2 in Canada. *Ecological Economics*, 69(5), 1083–1093. <https://doi.org/10.1016/j.ecolecon.2009.11.03>
- ITU. (2019). Database of the International telecommunication union. <https://datahub.itu.int/data/?e=701&c=&i=19303>
- Kaika, D., & Zervas, E. (2013). The Environmental Kuznets Curve (EKC) theory—part A: Concept, causes and the CO2 emissions case. *Energy Policy*, 62, 1392–1402. <https://doi.org/10.1016/j.enpol.2013.07.13>
- Khan, Y., Oubaih, H., & Elgourami, F. Z. (2022b). The effect of renewable energy sources on carbon dioxide emissions: Evaluating the role of governance, and ICT in Morocco. *Renewable Energy*, 190, 752–763. <https://doi.org/10.1016/j.renene.2022.03.140>

- Khan, Y., Oubaih, H., & Elgourrami, F. Z. (2022c). The role of private investment in ICT on carbon dioxide emissions (CO₂) mitigation: Do renewable energy and political risk matter in Morocco? *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-022-19455-w>
- Kifle, T. (2008a). Africa hit hardest by global warming despite its low greenhouse gas emissions. *Institute for World Economics and International Management Working Paper No. 108*. Accessed: 08/09/2015 <http://www.iwim.uni-bremen.de/publikationen/pdf/b108.pdf>
- Kiron, D., & Unruh, G., (2018). Sloan review MIT, *The convergence of digitalization and sustainability*. Retrieved 20 February 2018 from. <https://sloanreview.mit.edu/article/the-convergence-of-digitalization-and-sustainability/>
- Kopinina, H. (2020). Education for the future? Critical evaluation of education for sustainable development goals. *The Journal of Environmental Education*, 51(4), 280–291. <https://doi.org/10.1080/00958964.2019.1710444>
- Leal-Filho, W., Tripathi, S. K., Andrade Guerra, J. B. S. O. D., Gine-Garriga, R., Orlovic Lovren, V., & Willats, J. (2019a). Using the sustainable development goals towards a better understanding of Sustainability challenges. *International Journal of Sustainable Development & World Ecology*, 26(2), 179e190. <https://doi.org/10.1080/13504509.2018.1505674>
- Lee, J. W., & Brahmasrene, T. (2014). ICT, CO₂ Emissions and Economic Growth: Evidence from a Panel of ASEAN. *Global Economic Review*, 43(2), 93–109. <https://doi.org/10.1080/1226508X.2014.917803>
- Li, B., Liu, X., & Li, Z. (2015). Using the STIRPAT model to explore the factors driving regional CO₂ emissions: A case of Tianjin, China. *Natural Hazards*, 76(3), 1667–1685. <https://doi.org/10.1007/s11069-014-1574-9>
- Malmodin, J., & Bergmark, P. (2015). Exploring the effect of ICT solutions on GHG emissions in:2030. <https://doi.org/10.2991/ict4s-env-15.2015.5>
- Menyah, K., & Wolde-Rufael, Y. (2010). Energy consumption, pollutant emissions and economic growth in South Africa. *Energy Economics*, 32(6), 1374–1382. <https://doi.org/10.1016/j.eneco.2010.08.002>
- Murshed, M. (2020). An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia. *Environmental Science and Pollution Research*, 27(29), 36254–36281. <https://doi.org/10.1007/s11356-020-09497-3>
- Ozturk, I., & Acaravci, A. (2010). CO₂ emissions, energy consumption and economic growth in Turkey. *Renewable and Sustainable Energy Reviews*, 14(9), 3220–3225. <https://doi.org/10.1016/j.rser.2010.07.005>
- Penard, T., Poussing, N., Yebe, G. Z., & Ella, P. N. (2012). Comparing the determinants of internet and cell phone use in Africa: Evidence from Gabon. *Commun. Strateg*, 86(2), 65–83.
- Reed, W. R., & Ye, H. (2011). Which panel data estimator should I use? *Applied Economics*, 43(8), 985–1000. <https://doi.org/10.1080/00036840802600087>
- Sabau, G. (2020). The political economy of sustainability. *Sustainability*, 12(4), 1537. <https://doi.org/10.3390/su120415372020>
- Saboori, B., Sulaiman, J., & Mohd, S. (2016). Environmental Kuznets curve and energy consumption in Malaysia: A cointegration approach. *Energy Sources, Part B: Economics, Planning, and Policy*, 11(9), 861–867. <https://doi.org/10.1080/15567249.2012.662264>
- Shiu, A., & Lam, P. L. Causal relationship between telecommunications and economic growth: A study of 105 countries. *Proceedings of the 17th Biennial Conference of the International Telecommunications Society (ITS)*, Montreal, QC, Canada, 24–27 June 2008; Retrieved 10 June 2018 from. <http://www.imaginar.org/taller/its2008/192.pdf>
- Shurig, S. (2015). *Who will fund the renewable solution to the energy crisis?* The Guardian. Retrieved: 08 September 2015 from. <http://www.theguardian.com/global-development-professionalsnetwork/2014/jun/05/renewable-energy-electricity-africa-policy>
- Solow, R. (1974). The economics of resources or the resources of economics. *American Economic Review*, 64(2), 1–14. <http://www.jstor.org/stable/1816009>
- Tchamyou, V. S. (2016). The role of knowledge economy in African business. *The Journal of the Knowledge Economy*, 8(2017), 1189–1228. <http://dx.doi.org/10.1007/s13132-016-0417-1>
- Tony, F. L., & Kwan, D. S. (2015). African entrepreneurs and international coordination in petty businesses: The case of low-end mobile phones sourcing in Hong Kong. *J. Afr. Bus*, 16(1–2), 66–83.
- UN (United Nations). (2019b). *Report of the secretary-general on SDG progress 2019* (special ed.). United Nations. https://sustainabledevelopment.un.org/content/documents/24978Report_of_the_SG_on_SDG_Progress_2019.pdf
- WEF (World Economic Forum). (2020a). *Unlocking Technology for the Global Goals*, vol. 2020. World Economic Forum. Retrieved 17 March 2020 from. <https://www.weforum.org/reports/unlocking-technology-for-the-global-goals>
- World Bank. (2022). *Database of World Bank*. <https://databank.worldbank.org/source/world-development-indicators>
- York, R., Rosa, E. A., & Dietz, T. (2003). STIRPAT, IPAT and ImPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics*, 46(3), 351–365. [https://doi.org/10.1016/S0921-8009\(03\)00188-5](https://doi.org/10.1016/S0921-8009(03)00188-5)
- Zhang, C., & Liu, C. (2015). The impact of ICT industry on CO₂ emissions: A regional analysis in China. *Renewable and Sustainable Energy Reviews*, 44, 12–19. <https://doi.org/10.1016/j.rser.2014.12.011>
- Zhou, X., Zhou, D., & Wang, Q. (2018). How does information and communication technology affect China's energy intensity? A three-tier structural decomposition analysis. *Energy*, 151, 748–759. <https://doi.org/10.1016/j.energy.2018.03.115>

Appendix

Appendix 1. List of sample countries (38)
 Angola, Benin, Botswana, Burundi, Burkina Faso,
 Cameroon, Cabo Verde, Central African Republic, Congo
 Republic, Democratic Republic of Congo, Comoros, Cote

d'Ivoire, Eswatini, Equatorial Guinea, Gabon, Gambia,
 Ghana, Guinea, Guinea-Bissau, Kenya, Madagascar, Mali,
 Mauritius, Mauritania, Mozambique, Namibia, Niger,
 Nigeria, Rwanda, Sierra Leone, Senegal, Seychelles, South
 Africa, Tanzania, Togo, Uganda, Zambia, Zimbabwe.

Appendix 2. The description of Variables

Variables	Description	Source
Carbon emissions (metric tons)	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. Variables of interest.	WDI (2019)
Internet users	Internet users (in % of the population)	WDI (2019)
Mobile cellular subscribers	mobile phone penetration (in % of 100 people)	WDI (2019)
Per capital Gross Domestic Product	GDP per capita is gross domestic product divided by midyear population. Data are in current U.S. dollars	WDI (2019)
Population	Total number of inhabitation	WDI (2019)
Trade openness	Sum of export of good and services (% GDP)	

Appendix 3. Baseline regressions

Appendix 3A. Pooled OLS

	Linear specification		Nonlinear specification	
VARIABLES	CO2	CO2	CO2	CO2
<i>Mobile</i>	−0.180***		−0.130***	
	(0.0161)		(0.0198)	
<i>Mobile squared</i>			−0.0182	
			(0.0118)	
<i>Internet</i>		−0.136***		−0.141***
		(0.0441)		(0.0354)
<i>Internet squared</i>				0.00463
				(0.0203)
<i>GDPpc</i>	2.110***	1.676***	2.129***	1.730***
	(0.114)	(0.205)	(0.107)	(0.207)
<i>GDPpc squared</i>	−0.0606***	−0.0334**	−0.0595***	−0.0374**
	(0.00726)	(0.0129)	(0.00698)	(0.0133)
<i>Population</i>	1.057***	1.023***	1.056***	1.023***

(Continued)

(Continued)

	Linear specification		Nonlinear specification	
VARIABLES	CO2	CO2	CO2	CO2
	(0.0175)	(0.0105)	(0.0169)	(0.0104)
Trade openness	0.618***	0.538***	0.589***	0.543***
	(0.116)	(0.114)	(0.0854)	(0.0954)
Constant	−22.59***	−20.43***	−22.56***	−20.64***
	(0.725)	(0.977)	(0.572)	(0.577)
Observations	646	646	646	646
R-squared	0.895	0.881	0.897	0.881
Countries	38	38	38	38
Fisher	5150	8376	10162	29664
Fisher p-value	0.000	0.000	0.000	0.000

Notes: * p < 0.1; ** p < 0.05; *** p < 0.01; Standard errors in parentheses; all variables in log.

Appendix 3B. Fixed effect (FE)

	Linear specification		Nonlinear specification	
VARIABLES	CO2	CO2	CO2	CO2
Mobile	−0.0275***		−0.0290***	
	(0.00941)		(0.00948)	
Mobile squared			−0.00251	
			(0.00199)	
Internet		−0.0258*		−0.0258*
		(0.0136)		(0.0136)
Internet squared				9.89e-05
				(0.00244)
GDPpc	0.612***	0.466***	0.630***	0.468***
	(0.135)	(0.123)	(0.135)	(0.130)
GDPpc squared	−0.0265***	−0.0179**	−0.0265***	−0.0180**
	(0.00857)	(0.00806)	(0.00857)	(0.00853)
Population	1.493***	1.496***	1.573***	1.495***
	(0.108)	(0.129)	(0.125)	(0.133)
Trade openness	0.260***	0.248***	0.267***	0.248***
	(0.0376)	(0.0373)	(0.0379)	(0.0393)
Constant	−19.60***	−19.07***	−20.99***	−19.06***
	(1.688)	(1.956)	(2.013)	(1.974)
Observations	646	646	646	646
Countries	38	38	38	38

(Continued)

	Linear specification		Nonlinear specification	
VARIABLES	CO2	CO2	CO2	CO2
<i>R-squared</i>	0.731	0.729	0.731	0.729
<i>R-squared adj</i>	0.712	0.710	0.712	0.709
<i>Hausman test</i>	34.59***	43.82***	116.26	58.97
<i>Hausman p-value</i>	0.000	0.000	0.000	0.000
<i>Wald test</i>	2415.49***	2639.84***	2598.19	2619.01
<i>Wald p-value</i>	0.000	0.000	0.000	0.000
<i>Wooldrige test</i>	114.745	114.632	115.440	108.491
<i>Wooldrige pvalue</i>	0.000	0.000	0.000	0.000

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; Standard errors in parentheses; all variables in log.

Appendix 3C. Random Effect (RE)

	Linear specification		Nonlinear specification	
VARIABLES	CO2	CO2	CO2	lCO2
<i>mobile</i>	-0.0216**		-0.0207**	
	(0.00921)		(0.00929)	
<i>Mobile squared</i>			-0.000593	
			(0.00198)	
<i>Internet</i>		-0.000916		-0.00861
		(0.0115)		(0.0119)
<i>Internet squared</i>				0.00466*
				(0.00273)
<i>GDPpc</i>	0.828***	0.653***	0.828***	0.731***
	(0.150)	(0.137)	(0.151)	(0.144)
<i>GDPpc squared</i>	-0.0293***	-0.0206**	-0.0291***	-0.0254***
	(0.00961)	(0.00906)	(0.00959)	(0.00960)
<i>Population</i>	0.844***	0.798***	0.851***	0.793***
	(0.0468)	(0.0469)	(0.0495)	(0.0453)
<i>Trade openness</i>	0.366***	0.345***	0.367***	0.371***
	(0.0411)	(0.0412)	(0.0416)	(0.0431)
<i>Constant</i>	-11.22***	-9.684***	-11.33***	-10.02***
	(0.958)	(0.896)	(1.027)	(0.898)
<i>Observations</i>	646	646	646	646
<i>Countries</i>	38	38	38	38
<i>chi2</i>	1499	1477	1498	1478
<i>Chi2 p-value</i>	0.000	0.000	0.000	0.000

Notes: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; Standard errors in parentheses; all variables in log.

Source: Aunthors



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