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The Mobile Phone in Governance for Environmental Sustainability in Sub-Saharan Africa

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Abstract

In this study, we assess how the mobile phone can be leveraged upon to improve the role of governance in environmental sustainability in 44 Sub-Saharan African countries. The Generalised Method of Moments is used to establish policy thresholds. A threshold is a critical mass or level of mobile phone penetration at which the net effect of governance on Carbon dioxide (CO_2) emissions changes from positive to negative. Mobile phone penetration thresholds associated with negative conditional effects are: 36 (per 100 people) for political stability/no violence; 130 (per 100 people) for regulation quality; 146.66 (per 100 people) for government effectiveness; 65 (per 100 people) for corruption-control and 130 (per 100 people) for the rule of law. Practical and theoretical implications are discussed. The study provides thresholds of mobile phone penetration that are critical in complementing governance dynamics to reduce CO_2 emissions.

JEL Classification: C52; O38; O40; O55; P37
Keywords: CO2 emissions; ICT; Economic development; Africa

1. Introduction

How does governance unconditionally affect carbon dioxide (CO_2) emissions in Sub-Saharan Africa (SSA)? What is the role of information and communication technology (ICT) in the incidence of governance on CO_2 emissions in SSA? The two research questions underpinning this study are motivated by four contemporary trends in policy and scholarly circles, notably: (i) a great room for ICT penetration in the sub-region, (ii) concerns pertaining to environmental sustainability, (iii) governance challenges in addressing corresponding issues of environmental degradation and (iv) gaps in the literature. We may engage the points in turn.

First, recent literature is consistent with the fact that compared to more advanced economies (in Asia, Europe and North America), there is relatively more room for ICT penetration in SSA (see Penard et al., 2012; Tchamyou, 2017; Asongu, 2013; Asongu, 2018). Logically, the potential for such ICT can be leveraged to design solutions for post-2015 challenging global policy issues such as climate change and pollution of the environment.

Second, central to the post-2015 sustainable development agenda is a key theme of environmental sustainability (see Akpan et al., 2015; Asongu et al., 2016, 2017; Mbah & Nzeadibe, 2016). At least four motives relate this concern in SSA, notably: comparatively high economic growth, growing energy crises, consequences of global warming and unsound management of energy crises and corresponding pollution issues. The motives are substantiated in chronological order. (i) After lost decades from failed Structural Adjustment Programmes (SAPs), the sub-region has been enjoying an economic resurgence that began in the mid 1990s (see Fosu, 2015). Obviously, such a consistent trend in economic growth (which is associated with green house gas emissions) also represents important environmental challenges. This concern is even more obvious because SSA has recently been host to seven of the ten fastest growing economies in the world (see Asongu & Rangan, 2016). (ii) Energy crisis will dominate the contemporary policy agenda because it represents one of the most challenging policy syndromes among the sub-region's post-2015 development priorities (see Akinyemi et al., 2015). To put this assertion into perspective, the following points are noteworthy: borrowing from Shurig (2015) on findings from the International Energy Agency (IEA), energy access in SSA is about 5%; the total energy consumption in the sub-region is equivalent to that of a single state in the United States of America (USA) like New York and the consumption of electricity per capita in the sub-region is just about one-sixth of the global average. (iii) Whereas, it is obvious that global warming is a consequence of the increasing

and unsustainable consumption of fossil fuels around the globe (see Huxster et al., 2015), it is projected that the corresponding consequences of climate change will be largely borne by the population of Africa (see Kifle, 2008). It is important to note that the emission of CO_2 gases make-up approximately three-quarter of world greenhouse gas emissions (see Akpan, 2012). (iv) Concerns have also emerged about the ability of decision makers to manage underlying environmental challenges and energy crisis efficiently in most countries in SSA (see Anyangwe, 2014). For example, in countries like Nigeria, which is the most populated country in Africa, the substantial demand for fossil fuels is subsidized by the government while corresponding efforts devoted to engaging renewable and sustainable energy alternatives are low. As a result, generators are largely employed for the burning of subsidized petroleum fuel as a means of addressing electricity shortages and outages (see Apkan, 2012).

Third, one can logically infer from the above that energy crisis, corresponding government responses and related CO_2 emissions betray a serious governance issue in addressing the highlighted environmental challenges. This inference is in accordance with recent literature on policy challenges (Afful-Koomson, 2012; Hongwu, 2013). According to the narrative, there are governance deficiencies that are hindering efforts in the continent towards a green economy which need to be addressed if the continent is to achieve Sustainable Development Goals (SDGs).

Fourth, this study examines how ICT can complement governance for environmental sustainability with particular emphasis on decreasing CO_2 emissions. The positioning of the inquiry deviates from recent literature on CO_2 emissions which is skewed towards assessing relationships between economic growth, CO_2 emissions and energy consumption. Accordingly, the underlying literature has been characterised by two main strands. Whereas the first has focused on relationships between economic growth and environmental pollution, with recurrent articulation of the Environmental Kuznets Curve (EKC) hypothesis (see Akbostanci et al., 2009; Diao et al., 2009; He & Richard, 2010)[1], the second has been concerned with two principal research streams. On the one hand, linkages between economic growth, pollution and energy consumption and on the other hand, the nexus between economic prosperity and energy consumption. Whereas there is an abundant supply of literature in the latter stream (see Mehrara, 2007; Esso, 2010)[2], conflicting results have

[1] The EKC hypothesis is premised on the perspective that in the distant future, the nexus between income per capita and pollution of the environment has a U-shape form.
[2] The interested reader can find more insights in Olusegun (2008) and Akinlo (2009).

characterised the former stream which includes studies from Jumbe (2004), Ang (2007), Apergis and Payne (2009), Odhiambo (2009a, 2009b), Ozturk and Acaravci (2010), Menyah and Wolde-Rufael (2010), Bölük and Mehmet (2015) and Begum et al. (2015).

Noticeably in the highlighted mainstream literature is the absence of policy variables. In the present study, we argue that engaging policy variables is more likely to result in policy implications with more practical insights. Thus, conclusions based on relationships between the mainstream indicators (economic growth, CO_2 emissions and energy consumption) have less policy relevance because policy dimensions are not critically engaged in the empirics. We address this gap by using an ICT policy variable that could provide a more practicable way of addressing the sobering policy syndrome of environment pollution. The practical dimension of the policy variable is even more relevant in the light of its high potential for penetration in Africa (Tchamyou, 2017).

The present study unites the four strands above by assessing how ICT (in the first strand) can be leveraged with governance (discussed in the third strand) to tackle environmental issues (documented in the second strand) in order to complement extant literature (engaged in the fourth strand). The rest of the study is structured in the following manner. In Section 2, we discuss the intuition for and theoretical underpinnings of the study. The data and methodology are covered in Section 3 while Section 4 presents the empirical results. Concluding implications and future research directions are covered in Section 5.

2. Intuition and theoretical underpinnings

2.1 Linkages between poor governance and CO_2 emissions

According to Chemutai (2009), institutional challenges are associated with a growing number of concerns in Africa that are linked to *inter alia*: water scarcity, poverty, inequitable distribution of resources, food insecurity, loss of arable land and environmental degradation. The institutional challenges to environmental management are such that many countries in Africa are considerably strained by the underlying issues due to *inter alia*: lack of capacity to accommodate the changes owing to immense requirements and expectations from the international community. Chemutai (2009) maintains that many environmental institutions in Africa need a substantial overhaul of guiding principles, laws and policies for effective governance of the environment. While the narrative is expatiated by articulating the need for international donor agencies and developed countries to help African countries in the respect

of international environmental standards, our focus in this study is to assess how internal mechanisms such ICT can be used for environmental sustainability.

Owing to various governance issues, it has been difficult for African countries to implement Agenda 21[3]. Moreover, the implementation of Multilateral Environmental Agreements (MEAs) in the continent is not progressing accordingly because results are yet to be apparent (Jones, 2003; Chemutai, 2009). Some of documented institutional and policy challenges that lead to ineffective structures include, among others: the absence of adequate expertise, shortage of finance, lack of equipments and tools with which to enforce international conventions and laws on environmental protection, corporate unaccountability and trade policies. Accordingly, for a multitude of reasons, environmental channels and policies (such as more stringent measures of accountability for corporations) are associated with issues like CO_2 emissions.

In the light of the above, environmental challenges can be addressed if African nations improve on environmental governance. Hence addressing current constraints and weaknesses in Africa's environmental institutions is crucial in the post-2015 sustainable development agenda. Sound legislation, peace and security, political stability and more transparency in environmental protection and management procedures are essential for a sustainable reduction of CO_2 emissions in the continent. The issues can be addressed with enhanced political, economic and institutional governance mechanisms. The concepts of governance employed in this study are consistent with Kaufmann et al. (2010) and Andres et al. (2015). Within this conceptual setting: (i) political governance (understood as political stability/no violence and voice & accountability) is the election and replacement of political leaders; (ii) economic governance (proxied by government effectiveness and regulation quality) is the formulation of implementation of policies that deliver public commodities and (iii) institutional governance (measured with corruption-control and the rule of law) is the respect of citizens and the State of institutions that govern interactions between them.

Given the above, the testable hypotheses in this section build on the following three fundamentals. First, from the perspective of political governance, the ability of government to effectively prevent environmental pollution may be seriously constrained by the likelihood that the government can be overthrown and destabilized by violent and unconstitutional means. This is the dimension of political stability/no violence in political governance.

[3] Agenda 21 is a United Nation's voluntarily implemented plan of action that is non-binding with respect to sustainable development.

Moreover, the government's ability to effectively manage the environment could also be constrained by the lack of voice and accountability: the degree by which citizens of a country are able to take part in the process by which governments are selected. This extends to rights such as consumption of free media, freedom of association and freedom of expression.

Second, with respect to economic governance, environmental degradation can be substantially influenced by government effectiveness in environmental-related policies: the degree of quality in the process by which public services are delivered, how qualitative the policy formulation process is and how the government is credible when implementing policies that have been formulated. In addition, sound regulation quality is also crucial because in relation to environmental protection, it influences the government's capacity of implementing robust policies as well as in effectively communicating the attendant policies on the one hand and on the other, ensuring the enforcement of rules and guidelines that are relevant in enabling and promoting the development of the private sector.

Third, institutional governance is also very likely to influence the ability of government to effectively implement environmental protection measures. This can either be apparent from the extent to which: (i) agents are totally confident in and work towards abiding by societal rules and particularly the quality by which contracts are enforced, property rights are upheld, the police officers are effective and courts are efficient as well as the probability of occurrence of violence and crimes (which are within the remit of the rule of law) and/or (ii) there is an atmosphere that is favorable to the use of public power for private goals which encompass both substantial and moderate types of corruption as well as situations in which the State is captured by a few elite in quest for private interest.

In the light of the substantially documented evidence of poor governance in African countries (Obeng-Odoom, 2013, 2016; Fonchingong, 2014; Anyanwu & Erhijakpor, 2014; Efobi, 2015; Asongu & Nwachukwu, 2017), we do not expect governance to significantly improve environmental protection in the perspective of decreasing CO_2 emissions.

Hypothesis 1: Governance indicators are weak and do not influence CO_2 emissions.

This hypothesis is assessed with non-interactive regressions because the ICT policy variable is not engaged. Conversely, in a scenario where ICT is interacted with governance dynamics, the hypothesis of the policy relevance of ICT in complementing governance to influence CO_2 is assessed.

2.2 The intuition of ICT in dampening the effect of poor governance on CO_2 emissions

Chemutai (2009) has documented that in order to achieve environmental protection and sustainable development, the following elements are essential factors: accountability, transparency and information flow in public participation. The third factor can be translated as information flow in inclusive governance. The narrative maintains that in order to ensure good environmental systems, institutions need to be provided with the much needed resources that enable them to meet goals in the sustainable development agenda.

In the light of the above, communication which is essential for coordination in sound environmental governance is often neglected. Along this line of analysis, Chemutai (2009) has articulated that with respect to the United Nations Task Force on Environment and Human Settlements, effective governance of the environment can be achieved essentially via effective coordination. Moreover, according to the author, only effective communication strategies can lead to consistent guidance of agencies that are specialised in environmental management. In essence, for MEAs to be achieved, advanced communication between MEA secretariats is essential to mitigate the corresponding challenges (like false reporting) that confront governments.

The intuition of expecting ICT to complement governance in mitigating CO_2 emissions is twofold. On the one hand, ICT reduces informational rents and bureaucracy associated with political, economic and institutional governance (see Asongu & Nwachukwu, 2016a). On the other hand, ICT contributes towards information diffusion that ultimately contributes to environment sustainability. This is essentially because a mobile phone that is connected to the internet could: (i) reduce unnecessary travelling and attendant emissions of CO_2 from citizens and government officials and (ii) enhance household welfare and efficiency in public management via the employment of mobile applications that contribute towards saving-energy. This leads to the second testable hypothesis.

Hypothesis 2: Governance indicators can be complemented with ICT to affect CO_2 emissions.

3. Data and methodology

3.1 Data

This study investigates a panel of forty-four countries in SSA with data from World Governance Indicators and World Development Indicators of the World Bank for the period

2000-2012[4]. The choice of the periodicity is contingent on constraints in data availability. The main dependent variable is CO_2 emissions per capita whereas the ICT policy variable is measured with mobile phone penetration (per 100 people), consistent with recent knowledge economy literature (Asongu & Nwachukwu, 2016a; Tchamyou, 2017).

The study uses six main governance dynamics or variables which are categorised in terms of: (i) political governance (representing no violence/political stability as well as accountability and voice); (ii) economic governance (reflecting regulation quality and the effectiveness of government) and (iii) institutional governance (covering the rule of law and the control of corruption). The source of these governance dynamics is Kaufmann et al. (2010). They are also consistent with the relevant governance literature, notably: Gani (2011), Yerrabit and Hawkes (2015), Andrés et al. (2015) and Oluwatobi et al. (2015).

Four main control variables are used in order to avoid variable omission bias, namely: Gross Domestic Product (GDP) growth rate, population growth, educational quality and trade openness. The adopted control measures reflect globalization (trade openness), market (population growth and GDP growth) and knowledge (educational quality) variables that are likely to influence environmental pollution. Whereas we expect educational quality to reduce CO_2 emissions and the other three control variables to have the opposite impact, such an intuition should be acknowledged with caution because the overall effect may be substantially contingent on market and industrial dynamics. Moreover, country-specific effects may weigh substantially in the determination of expected signs. It is important to note that these country-specific effects are eliminated from the adopted Generalised Method of Moments (GMM), which is our empirical strategy. The full definitions of variables, corresponding summary statistics and correlation matrix are disclosed in Appendix 1, Appendix 2 and Appendix 3, respectively.

3.2 Methodology

3.2 1 Specification

The GMM empirical strategy is adopted by this study for four main reasons (Vu & Asongu, 2020). First, the baseline condition for the employment of the technique is met

[4] The 44 countries are: Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo Democratic. Republic., Congo Republic, Cote d'Ivoire, Djibouti, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome & Principe, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda and Zambia.

because the number of countries (which is forty-four) is substantially higher than the corresponding number of periods in each country (which is thirteen). Second, the dependent variable is persistent because its correlation with its corresponding first lag value is higher than the rule of thumb threshold of 0.800. It is important to note that the use of GMM requires that the outcome variable should be persistent and such persistence is confirmed (as in contemporary GMM-centric literature) when the coefficient of correlation between the level and first lag series is higher than 0.800 (Tchamyou, 2019, 2020). Moreover, one lag is enough capture past information because in the light of the persistence criterion, only one lag is enough to capture past information. The notion of persistence is premised on the perspective that present observations of the outcome variable significantly depend on past observations of the same outcome variable. Third, cross-country disparities are not eliminated from the estimation approach because the estimation strategy is consistent with a panel data structure. Fourth, the estimation technique further accounts for endogeneity by controlling for simultaneity in the explanatory variables using an instrumentation process. Moreover, the employment of time-invariant indicators also enables the study to control for endogeneity in the perspective of the unobserved heterogeneity.

The adopted GMM approach is the Roodman (2009a, 2009b) extension of Arellano and Bover (1995) because relative other GMM estimation strategies, it has been documented to reduce instrument proliferation and limit over-identification (see Love & Zicchino, 2006; Baltagi, 2008; Tchamyou & Asongu, 2017; Boateng et al., 2018).

The following equations in level (1) and first difference (2) summarise the standard *system* GMM estimation procedure.

$$CO_{i,t} = \sigma_0 + \sigma_1 CO_{i,t-\tau} + \sigma_2 I_{i,t} + \sigma_3 G_{i,t} + \sigma_4 IG_{i,t} + \sum_{h=1}^{4} \delta_h W_{h,i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t} \quad (1)$$

$$\begin{aligned} CO_{i,t} - CO_{i,t-\tau} = {} & \sigma_1 (CO_{i,t-\tau} - CO_{i,t-2\tau}) + \sigma_2 (I_{i,t} - I_{i,t-\tau}) + \sigma_3 (G_{i,t} - G_{i,t-\tau}) + \sigma_4 (IG_{i,t} - IG_{i,t-\tau}) \\ & + \sum_{h=1}^{4} \delta_h (W_{h,i,t-\tau} - W_{h,i,t-2\tau}) + (\xi_t - \xi_{t-\tau}) + (\varepsilon_{i,t} - \varepsilon_{i,t-\tau}) \end{aligned} \quad (2)$$

where, $CO_{i,t}$ is a CO_2 emissions proxy of country i in period t, σ_0 is a constant, I represents an ICT indicator (i.e. penetration of mobile phones), G is a governance variable (political stability, regulation quality, voice & accountability, rule of law, government effectiveness and corruption-control), IG is the interaction of a governance dynamic with an ICT proxy, W is the vector of control variables (trade, GDP growth, education quality and population growth), τ reflects the auto-regression coefficient that is considered to be one in

the present specification because one lag appropriately captures non-contemporary information, ξ_t represents the constant that is time-specific, η_i is the country-specific effect and $\varepsilon_{i,t}$ the error term. The fact that there is a lagged value of the outcome variable on the right hand-side of the equations shows the dynamic nature of the modelling exercise, not least, because contemporary values of the outcome variable are also explained by non-contemporary values of the same outcome variable.

It is important to note that, the specifications enable the computation of net effects and/or thresholds in order to avoid pitfalls of interactive regressions as documented in Brambor et al. (2006). Accordingly, consistent with contemporary interactive regressions literature (Asongu et al., 2020, 2021), in order to avoid the attendant pitfalls, the estimates are not interpreted as in linear additive models and hence, both the conditional (or interactive) and the unconditional effect should be considered when assessing the full incidence of the moderating variables on the investigated channels to influence the outcome variable. Moreover, other thresholds methods such as the Hansen threshold approach are not appropriate owing to data availability constraints. Accordingly, due to the unbalanced structure of the dataset, the underlying alternative technique which is designed for nonlinear estimations cannot be appropriately used, namely: the Hansen (1999) Panel Threshold Regression (PTR) technique and Panel Smooth Transition Regression (PSTR) from González et al. (2005) and González et al. (2017).

3.1.2 Identification, simultaneity and exclusion restrictions

We briefly discuss issues surrounding identification, simultaneity and exclusion restrictions that are critical for a robust GMM specification. First, with regard to identification, all explanatory variables are considered as predetermined or suspected endogenous and only variables that are time invariant are acknowledged to be strictly exogenous. This identification procedure is consistent with recent empirical literature (see Asongu & Nwachukwu, 2016b, Boateng et al., 2018; Tchamyou et al, 2019a, 2019b). This is essentially because the time-invariant variables or years are unlikely to become endogenous after a first difference (see Roodman, 2009b)[5].

Second, with respect to simultaneity, lagged regressors are employed as instruments for indicators that are forward-differenced. In essence, the fixed effects that could eventually

[5] Hence, the procedure for treating *ivstyle* (years) is 'iv (years, eq(diff))' whereas the *gmmstyle* is employed for predetermined variables.

influence the assessed relationships are purged using Helmert transformations on the regressors (see Arellano & Bover, 1995; Love & Zicchino, 2006). Such a transformation entails forward average-differencing of the indicators: the average of all future observations is subtracted from the indicators, contrary to deducting past observations from the present ones. These conversions permit orthogonal or parallel conditions between lagged values and forward-differenced indicators. Irrespective of the number of lags, in order to avoid data loss as much as possible, the suggested transformations are engaged for all observations, with the exception of the last observation for each cross section.

Third, concerning exclusion restrictions, the time invariant variables influence CO_2 emissions exclusively through the suspected endogenous or predetermined variables. Moreover, the statistical validity of the exclusion restriction is investigated with the Difference in Hansen Test (DHT) for the exogeneity of instruments. Accordingly, the alternative hypothesis of the DHT should be rejected in order for the time invariant variables to affect CO_2 emissions exclusively through the suspected endogenous variables. Therefore, in the results that are presented subsequently, the hypothesis of exclusion restriction is validated if the null hypothesis of the DHT related to instrumental variables (IV) (year, eq(diff)) is not rejected. The information criterion is broadly consistent with the standard IV procedure in which, a rejection of the alternative hypothesis of the Sargan Overidentifying Restrictions (OIR) test implies that strictly exogenous variables affect CO_2 emissions exclusively via the suspected endogenous variable channels (see Beck et al., 2003; Asongu & Nwachukwu, 2016c).

4. Empirical results

Table 1 and Table 2 present empirical results corresponding to *Hypothesis* 1 and *Hypothesis* 2. The latter (former) is based on interactive (non-interactive) regressions in which an ICT policy variable is engaged (not engaged) to complement governance variables for the overall impact on CO_2 emissions. Each table has six specifications denoting each governance dynamic.

Table 1: Governance and CO_2 emissions (Non-interactive for Hypothesis 1)

	Dependent Variable: CO_2 per capita emissions					
	Political Governance		Economic Governance		Institutional Governance	
Constant	**0.237*** **	**0.255*** **	**0.397*** **	**0.322*** **	**0.330*** **	**0.384*** **
	(0.000)	**(0.001)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
CO_2 per capita (-1)	**0.925*** **	**0.921*** **	**0.909*** **	**0.918*** **	**0.914*** **	**0.894*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Political Stability	0.019	---	---	---	---	---
	(0.400)					
Voice & Accountability	---	0.0004	---	---	---	---
		(0.988)				
Regulation Quality	---	---	-0.018	---	---	---
			(0.740)			
Government Effectiveness	---	---	---	0.023	---	---
				(0.549)		
Corruption Control	---	---	---	---	-0.004	---
					(0.880)	
Rule of Law	---	---	---	---	---	0.051
						(0.353)
GDP growth	-0.0009	-0.001	-0.001	-0.001	-0.001	-0.0004
	(0.549)	(0.488)	(0.524)	(0.337)	(0.321)	(0.786)
Popg	**-0.076*** **	**-0.075*** **	**-0.087*** **	**-0.091*** **	**-0.084*** **	**-0.079*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Education	0.0002	-0.0004	-0.002	-0.0006	-0.001	**-0.002***
	(0.813)	(0.731)	(0.107)	(0.540)	(0.241)	**(0.053)**
Trade Openness	0.0002	-0.00005	-0.0003	-0.00002	-0.0001	0.0001
	(0.401)	(0.883)	(0.391)	(0.943)	(0.435)	(0.994)
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes
AR(1)	**(0.105)**	**(0.107)**	**(0.106)**	**(0.109)**	**(0.106)**	**(0.108)**
AR(2)	**(0.209)**	**(0.208)**	**(0.206)**	**(0.205)**	**(0.206)**	**(0.204)**
Sargan OIR	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Hansen OIR	**(0.826)**	**(0.934)**	**(0.852)**	**(0.531)**	**(0.779)**	**(0.942)**
DHT for instruments						
(a)Instruments in levels						
H excluding group	**(0.546)**	**(0.445)**	**(0.690)**	**(0.677)**	**(0.502)**	**(0.688)**
Dif(null, H=exogenous)	**(0.822)**	**(0.978)**	**(0.782)**	**(0.381)**	**(0.787)**	**(0.924)**
(b) IV (years, eq(diff))						
H excluding group	**(0.810)**	**(0.747)**	**(0.869)**	**(0.347)**	**(0.630)**	**(0.862)**
Dif(null, H=exogenous)	**(0.637)**	**(0.899)**	**(0.627)**	**(0.630)**	**(0.716)**	**(0.835)**
Fisher	**12439*** **	**13116*** **	**6547*** **	**11476*** **	**11523*** **	**7202*** **
Instruments	32	32	32	32	32	32
Countries	44	44	44	44	44	44
Observations	340	340	340	340	340	340

*,**,***: significance levels of 10%, 5% and 1% respectively. DHT: Difference in Hansen Test for Exogeneity of Instruments' Subsets. Dif: Difference. OIR: Over-identifying Restrictions Test. The significance of bold values is twofold. 1) The significance of estimated coefficients and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) and AR(2) tests and; b) the validity of the instruments in the Sargan and Hansen OIR tests. The government variables are correlated significantly between each other and therefore they need to be introduced one after the other in the modelling.

Table 2: Mobile phones, Governance and CO_2 emissions (Interactive for Hypothesis 2)

	Dependent Variable: CO_2 per capita emissions					
	Political Governance		Economic Governance		Institutional Governance	
Constant	**0.202*** **	**0.336*** **	**0.473**	**0.320*** **	**0.357*** **	**0.371*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
CO_2 per capita (-1)	**0.933*** **	**0.914*** **	**0.907*** **	**0.927*** **	**0.901*** **	**0.895*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Mobile phone (Mob)	0.0005	-0.0001	**-0.0006****	-0.0002	0.0004	**0.0004***
	(0.150)	(0.717)	**(0.036)**	(0.257)	(0.164)	**(0.093)**
Political Stability	**0.018****	---	---	---	---	---
	(0.026)					
Voice & Accountability	---	**0.036*** **	---	---	---	---
		(0.036)				
Political Governance	---	---	---	---	---	---
Regulation Quality	---	---	**0.039****	---	---	---
			(0.011)			
Government Effectiveness	---	---	---	**0.044*** **	---	---
				(0.000)		
Corruption Control	---	---	---	---	**0.039*** **	---
					(0.007)	
Rule of Law	---	---	---	---	---	**0.052*** **
						(0.002)
Political Stability×Mob	**-0.0005*** **	---	---	---	---	---
	(0.003)					
Voice & Accountability×Mob	---	-0.00005	---	---	---	---
		(0.730)				
Regulation Quality×Mob	---	---	**-0.0003***	---	---	---
			(0.094)			
Government Effectiveness×Mob	---	---	---	**-0.0003***	---	---
				(0.096)		
Corruption Control×Mob	---	---	---	---	**-0.0006*** **	---
					(0.006)	
Rule of Law×Mob	---	---	---	---	---	**-0.0004***
						(0.054)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes
Net Effects	0.0057	na	0.0316	0.0366	0.0243	0.0422
AR(1)	**(0.103)**	**(0.107)**	**(0.105)**	**(0.106)**	**(0.113)**	**(0.110)**
AR(2)	**(0.204)**	**(0.206)**	**(0.207)**	**(0.207)**	**(0.206)**	**(0.204)**
Sargan OIR	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Hansen OIR	**(0.735)**	**(0.987)**	**(0.793)**	**(0.662)**	**(0.856)**	**(0.869)**
DHT for instruments						
(a)Instruments in levels						
H excluding group	**(0.605)**	**(0.793)**	**(0.831)**	**(0.782)**	**(0.836)**	**(0.800)**
Dif(null, H=exogenous)	**(0.675)**	**(0.960)**	**(0.609)**	**(0.459)**	**(0.711)**	**(0.750)**
(b) IV (years, eq(diff))						
H excluding group	**(0.925)**	**(0.936)**	**(0.599)**	**(0.503)**	**(0.879)**	**(0.739)**
Dif(null, H=exogenous)	**(0.276)**	**(0.873)**	**(0.806)**	**(0.693)**	**(0.571)**	**(0.797)**
Fisher	**34352*** **	**36527*** **	**27774*** **	**33068*** **	**24698*** **	**14653*** **
Instruments	40	40	40	40	40	40
Countries	44	44	44	44	44	44
Observations	339	339	339	339	339	339

*,**,***: significance levels of 10%, 5% and 1% respectively. DHT: Difference in Hansen Test for Exogeneity of Instruments' Subsets. Dif: Difference. OIR: Over-identifying Restrictions Test. The significance of bold values is twofold. 1) The significance of estimated coefficients and the Fisher statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(1) and AR(2) tests and; b) the validity of the instruments in the Sargan and Hansen OIR tests. na: not applicable because at least one estimated coefficient needed for the computation of net effects is not significant. The mean of mobile phone penetration is 24.428. The government variables are correlated significantly between each other and therefore they need to be introduced one after the other in the modelling.

The estimated coefficients corresponding to the governance variables are used to assess the relevance of *Hypothesis* 1 whereas net effects are employed to examine if *Hypothesis* 2 is valid or not. For either hypothesis, four information criteria are used to investigate the validity of GMM models[6]. Moreover, for the *Hypothesis* 2, net effects of governance and ICT thresholds are computed to examine the overall impact of the complementarity between ICT and governance in CO_2 emissions. For instance, in the second column of Table 2, the net effect from the interaction between mobile phones and political stability is 0.0057 ([-0.0005× 24.428] + [0.018]). In the computation, the mean value of mobile phone penetration is 24.428, the unconditional impact of mobile phone penetration is 0.0018 while the conditional impact from the interaction between political governance and mobile phones is -0.0005. In the investigation of either hypothesis, a decrease in the outcome variable implies positive conditions for environmental sustainability.

In Table 1, it is apparent that governance variables do not significantly influence per capita CO_2 emissions. With regard to Table 2, positive net effects are established in five of the six specifications. Fortunately, the corresponding conditional effects are negative. The implication of these negative conditional effects is that, at certain thresholds of mobile phone penetration, the net effect can be changed from positive to negative. However, in order for these thresholds to make economic sense and have policy relevance, they must be within the range of the data (i.e. minimum to maximum values in the corresponding summary statistics). It is relevant to clarify the notion of critical mass before computing corresponding thresholds.

The notion of threshold or critical mass in this study can be understood as the level of mobile phone penetration (per 100 people) at which the interaction between the mobile phone and a governance indicator yields a net negative effect on CO_2 emissions[7]. The logical policy implication is that, if the established threshold is within range, policy makers will need to enhance the enabling environment for ICT penetration so that the policy threshold is

[6] "*First, the null hypothesis of the second-order Arellano and Bond autocorrelation test (AR (2)) in difference for the absence of autocorrelation in the residuals should not be rejected. Second the Sargan and Hansen over-identification restrictions (OIR) tests should not be significant because their null hypotheses are the positions that instruments are valid or not correlated with the error terms. In essence, while the Sargan OIR test is not robust but not weakened by instruments, the Hansen OIR is robust but weakened by instruments. In order to restrict identification or limit the proliferation of instruments, we have ensured that instruments are lower than the number of cross-sections in most specifications. Third, the Difference in Hansen Test (DHT) for exogeneity of instruments is also employed to assess the validity of results from the Hansen OIR test. Fourth, a Fisher test for the joint validity of estimated coefficients is also provided*" (Asongu & De Moor, 2017, p.200).

[7] Thresholds can be established both with quadratic regression (i.e. in which squared terms are used) and interactive regressions (i.e. in which distinct variables are interacted) regressions. For this specific study, in the light of the problem statement, interactive regressions are needed to established thresholds (i.e. governance dynamics and the mobile phone are interacted to assess their relevance on CO2 emissions). It follows that interactive regressions from which thresholds are established, are consistent with the second research question and second hypothesis.

achieved. This threshold notion is consistent with *inter alia*: critical masses for appealing impacts (Roller & Waverman, 2001; Batuo, 2015); conditions for U-shaped and inverted U-shaped curves (see Ashraf & Galor, 2013), minimum requirements to obtain desired impacts (Cummins, 2000) and essential information sharing critical masses at which market power can be reduced in order to enhance financial intermediation efficiency (Asongu et al., 2019).

The following are the corresponding critical thresholds of mobile phone penetration: (i) 36(0.018/0.0005) for the association with political stability/no violence; (ii) 130 (0.039/0.0003) for the association with regulation quality; (iii) 146.66 (0.044/0.0003) for the interaction with government effectiveness; (iv) 65 (0.039/0.0006) for the relationship with corruption-control and (v) 130 (0.052/0.0004) for the complementarity with the rule of law. Given that the mobile penetration range is between 0.000 and 147.202 (per 100 people), the computed thresholds make economic sense and have policy relevance. It follows that above these thresholds, the mobile phone can significantly complement governance dynamics in reducing CO_2 emissions.

5. Concluding implications and future research directions

In this study, we have assessed how the mobile phone can be used to enhance the role of governance in environmental sustainability in 44 Sub-Saharan African countries. The empirical evidence is based on the Generalised Method of Moments. Six governance dynamics are used, namely: political governance (voice & accountability and political stability/no violence); economic governance (government effectiveness and regulation quality) and institutional governance (corruption-control and the rule of law). The following findings have been established. First, in non-interactive regressions, all governance variables do not significantly affect Carbon dioxide (CO_2) emissions. Second, from interactive regressions, net positive effects are established in five of the six complementarities between the mobile phone and governance dynamics. Fortunately, corresponding conditional effects from interactions are negative. Mobile phone penetration thresholds associated with these negative conditional effects are within range, notably: 36 (per 100 people) for political stability/no violence; 130 (per 100 people) for regulation quality; 146.66 (per 100 people) for government effectiveness; 65 (per 100 people) for corruption-control and 130 (per 100 people) for the rule of law. We now discuss practical and theoretical implications.

On the practical dimension, it is relevant to increase mobile penetration to a maximum (or 147 per 100 people) because a penetration rate of more than 146 per 100 people is required for the interaction between government effectiveness and the mobile phone to reduce CO_2 emissions. In order for the mobile phones to be consolidated beyond the critical masses which have been identified, it is relevant for policy makers to address concerns pertaining to the lack of good mobile phone infrastructure. Moreover, policies that encourage low pricing and universal coverage will also ensure that the mobile phone plays the role of an interface between government policies and channels through which CO_2 emissions are reduced.

While the net effects are positive, mobile phone penetration thresholds are provide so that if they are exceeded, the net effects become negative. Accordingly, countries are recommended to exceed the established mobile phone penetration thresholds in order for the interaction between mobile phones and governance to induce net negative effects on the CO2 emissions. Both mobile phone penetration and governance variables can be acted upon by sampled countries. Hence, both variables have policy relevance and policy makers can implement policies to increase the mobile phone penetration rate to the established thresholds, not least, because compared to other developing countries, ICT penetration in SSA is relatively lower (Tchamyou, 2017). Hence, there is a potential for ICT penetration which policy makers can leverage upon.

In the light of the above, the role of ICT in environmental governance in Africa is crucial for achieving sustainable development goals in the post-2015 development agenda. Hence, in order to valorize Agenda 21 and Multilateral Environmental Agreements (MEAs) (which are not progressing accordingly) in the continent, regulatory procedures in the protection and management of the environment should be implemented concurrently with measures aimed at boosting ICT penetration. This synergy or complementarity will enhance coordination between various government sectors in the maintenance of sustainable development efforts. For example, Rwanda is currently consolidating its Rwanda Information Technology Authority (RITA) which enhances and coordinates the country's resources in information technology (Chemutai, 2009). Such an initiative can be borrowed by other countries in SSA in view of enhancing information flow across sectors focused on environmental sustainability.

The theoretical implication of the study fundamentally borders around the role of the mobile phone as an information sharing device. Accordingly, we have shown that by sharing information, the mobile can potentially reduce information asymmetry between various

governance departments. Hence, by sharing information and increasing transparency, informational rents that were previously enjoyed by a few elite in government institutions can be reduced substantially. Such informational rents are positively associated with cost and traffic linked to CO_2 emissions. To put this point into perspective, a quick exchange of information (with the dial of a mobile phone) between various agencies of government can reduce transportation costs that would have been incurred for the staff in the associated government departments in order to physically meet for the purpose of exchanging the information. With insights from this clarification, the relevance of mobile phones in reducing informational rents that are linked to environmental degradation and/or CO_2 emissions is broadly in accordance with the theoretical basis of efficiency in financial intermediation by means of information sharing offices (such as private credit bureaus and public credit registries) (see Asongu et al., 2016c).

Therefore, given the underlying analogy, the theoretical background for consolidating financial intermediation through information sharing bureaus is in accordance with complementing the mobile phone with governance in order to reduce information asymmetry that increases CO_2 emissions. Future research can consolidate the existing literature by investigating if the established relationships withstand further empirical scrutiny within country-specific standpoints. Such country-specific inquiries are also relevant for more targeted policy implications.

Appendices

Appendix 1: Definitions of variables

Variables	Abbreviations	Variable Definitions (Measurements)	Sources
CO_2 per capita	CO2mtpc	CO_2 emissions (metric tons per capita)	World Bank (WDI)
Mobile phones	Mobile	Mobile phone subscriptions (per 100 people)	World Bank (WDI)
GDP growth	GDPg	Gross Domestic Product (GDP) growth (annual %)	World Bank (WDI)
Population growth	Popg	Population growth rate (annual %)	World Bank (WDI)
Educational Quality	Educ	Pupil teacher ratio in Primary Education	World Bank (WDI)
Trade Openness	Trade	Imports plus Exports of goods and services (% of GDP)	World Bank (WDI)
Political Stability	PolS	"Political stability/no violence (estimate): measured as the perceptions of the likelihood that the government will be destabilized or overthrown by unconstitutional and violent means, including domestic violence and terrorism".	World Bank (WDI)
Voice & Accountability	VA	"Voice and accountability (estimate): measures the extent to which a country's citizens are able to participate in selecting their government and to enjoy freedom of expression, freedom of association and a free media"	World Bank (WDI)
Government Effectiveness	GE	"Government effectiveness (estimate): measures the quality of public services, the quality and degree of independence from political pressures of the civil service, the quality of policy formulation and implementation, and the credibility of governments' commitments to such policies".	World Bank (WDI)
Regulation Quality	RQ	"Regulation quality (estimate): measured as the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development"	World Bank (WDI)
Corruption-Control	CC	"Control of corruption (estimate): captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as 'capture' of the state by elites and private interests"	World Bank (WDI)
Rule of Law	RL	"Rule of law (estimate): captures perceptions of the extent to which agents have confidence in and abide by the rules of society and in particular the quality of contract enforcement, property rights, the police, the courts, as well as the likelihood of crime and violence"	World Bank (WDI)

WDI: World Bank Development Indicators.

Appendix 2: Summary statistics (2000-2012)

	Mean	SD	Minimum	Maximum	Observations
CO_2 per capita	0.901	1.820	0.016	10.093	567
Mobile phone penetration	24.428	28.535	0.000	147.202	525
GDP growth	4.851	5.000	-32.832	33.735	567
Population growth	2.334	0.866	-1.081	6.576	529
Educational Quality	43.784	14.731	12.466	100.236	425
Trade Openness	76.881	35.326	20.964	209.874	555
Political Stability	-0.481	0.920	-2.660	1.192	528
Voice & Accountability	-0.540	0.676	-1.838	0.990	528
Government Effectiveness	-0.698	0.582	-1.960	0.934	528
Regulation Quality	-0.602	0.538	-2.110	0.983	528
Corruption Control	-0.589	0.563	-1.566	1.249	528
Rule of Law	-0.661	0.614	-2.113	1.056	528

S.D: Standard Deviation.

Appendix 3: Correlation matrix(uniform sample size: 373)

Governance Dynamics						Control Variables				Mobile	CO2mtpc	
PolS	VA	GE	RQ	CC	RL	GDPg	Popg	Educ	Trade			
1.000	0.715	0.673	0.629	0.718	0.811	-0093	-0.332	-0.361	0.268	0.319	0.311	PolS
	1.000	0.759	0.706	0.719	0.827	-0.005	-0.254	-0.399	0.097	0.309	0.401	VA
		1.000	0.880	0.861	0.892	-0.001	-0.398	-0.399	0.111	0.364	0.549	GE
			1.000	0.779	0.831	-0.073	-0.280	-0.310	0.062	0.296	0.384	RQ
				1.000	0.868	-0.062	-0.443	-0.431	0.183	0.360	0.429	CC
					1.000	-0.043	-0.366	-0.419	0.211	0.349	0.434	RL
						1.000	0.196	0.130	-0.034	-0.094	-0.088	GDPg
							1.000	0.445	-0.446	-0.407	-0.524	Popg
								1.000	-0.388	-0.445	-0.449	Educ
									1.000	0.325	0.187	Trade
										1.000	0.521	Mobile
											1.000	CO2mtpc

PolS: Political Stability. VA: Voice & Accountability. GE: Government Effectiveness. RQ: Regulation Quality. CC: Corruption-Control. RL: Rule of Law. GDPg: GDP growth. Popg: Population growth. Educ: Educational Quality Trade: trade openness. Mobile: Mobile phone penetration. CO2mtpc: CO_2 emissions (metric tons per capita).

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