European Xtramile Centre of African Studies (EXCAS)

EXCAS Working Paper

WP/19/010

Economic Development Thresholds for a Green Economy in Sub-Saharan Africa[1]

Forthcoming: Energy Exploration & Exploitation

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[1] This working paper also appears in the Development Bank of Nigeria Working Paper Series.

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Economic Development Thresholds for a Green Economy in Sub-Saharan Africa

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January 2019

Abstract

This study investigates how increasing economic development affects the green economy in terms of CO2 emissions, using data from 44 countries in the SSA for the period 2000-2012. The Generalised Method of Moments (GMM) is used for the empirical analysis. The following main findings are established. First, relative to CO2 emissions, enhancing economic growth and population growth engenders a U-shaped pattern whereas increasing inclusive human development shows a Kuznets curve. Second, increasing GDP growth beyond 25% of annual growth is unfavorable for a green economy. Third, a population growth rate of above 3.089% (i.e. annual %) has a positive effect of CO2 emissions. Fourth, an inequality-adjusted human development index (IHDI) of above 0.4969 is beneficial for a green economy because it is associated with a reduction in CO2 emissions. The established critical masses have policy relevance because they are situated within the policy ranges of adopted economic development dynamics.

JEL Classification: C52; O38; O40; O55; P37

Keywords: CO2 emissions; Economic development; Africa

1. Introduction

What thresholds of economic development are associated with reversals in carbon dioxide (CO_2) emissions in sub-Saharan Africa (SSA)? The positioning of this study on thresholds of economic development for a green economy in sub-Saharan Africa (SSA) is motivated by two main factors in scholarly and policy-making circles, notably: the relevance of the green economy in the post-2015 development agenda and gaps in the extant literature

First, the green economy is a central theme in sustainable development goals (SDGs) because, *inter alia*, greenhouse gas emissions are a great challenge to the sustainability of the global environment in the post-2015 development agenda (Shaw & Bachu, 2012; Collett, 2012; Akinyemi *et al*., 2015; Akpan *et al*., 2015; Mbah & Nzeadibe, 2016; Asongu *et al*., 2016a; Rui *et al*., 2017; Efobi *et al*., 2018; Akinyemi *et al*., 2018). Moreover, as documented by Asongu (2018a), the consequences of global warming are most detrimental to countries in Africa for numerous reasons, notably: (i) rampant crises in environmental pollution, persistence in energy crisis and (ii) the ramifications of mismanagement of energy across the continent. These fundamental factors are explained in elaborate detail in the following passages.

On the front of mismanagement, consistent with the attendant literature (Anyangwe, 2014; Odhiambo, 2010, 2014a; Asongu *et al*., 2017, 2018), the energy sector of many countries in SSA is not being managed properly, especially when it pertains to less investment in renewable energy and more allocation of funds to the subsidisation of fossil fuels. It is worthwhile to emphasise that economic prosperity in the lasttwo centuries has been fundamentally reliant on energy availability which is indispensible for economic processes, *inter alia*: production, distribution and consumption activities (Odhiambo, 2009a, 2009b, 2014b). One very glaring case of the inability of policy makers to come up with effective renewable energy policies is the case of Nigeria where instead of promoting sustainable energy sources, fossil fuels are subsidised (Apkan & Apkan, 2012).

Concerning the persistence of CO_2, whereas these emissions makeup about 75% of global greenhouse emissions (Akpan & Akpan, 2012), there are many accounts that are in accordance with the view that the unfavorable ramifications of climate change will be most apparent in SSA (Shurig, 2015; Kifle, 2008; Asongu, 2018b). Accordingly, this change of climate is an immediate consequence of fossil fuels that are consumed unsustainably (Huxster *et al.*, 2015). Moreover, approximately 620 million of inhabitants in SSA (which represents about two-thirds of the population) lack access to electricity (World Energy Outlook 2014 Factsheet). This substantially contrasts with the growing demand for energy in the sub-region which: (i) represents about 4% of the global demand and (ii) increased by approximately 45% during the period 2000-2012 (World Energy Outlook 2014 Factsheet).

Second, the extant literature on linkages between the consumption of energy, CO2 emissions and development outcomes can be classified in two main categories: while the first emphasises the relationships between environmental degradation and economic growth, the second strand is concerned with associations between energy consumption and economic development. Two sub-strands are apparent in the second strand, notably: (i) research focusing on linkages between energy consumption and economic development (Jumbe, 2004; Ang, 2007; Apergis & Payne, 2009; Odhiambo, 2009a, 2009b; Ozturk & Acaravci, 2010; Menyah & Wolde-Rufael, 2010; Bölük & Mehmet, 2015; Begum *et al.*, 2015) and enquires into relationships between energy consumption, environmental degradation and economic prosperity (Mehrara, 2007; Olusegun, 2008; Akinlo, 2008; Esso, 2010).

The second strand which is more related to the positioning of this research underlines the investigation of the Environmental Kuznets Curve (EKC)[2] hypothesis (Diao *et al.*, 2009; Akbostanci *et al.*, 2009; He & Richard, 2010). The attendant literature pertaining to the EKC has largely focused on the nexus between environmental degradation and per capita income. This research departs from the underlying literature on two fronts. On the one hand, we contribute to the EKC literature by investigating the relationship between environmental degradation and economic development using three outcome variables, namely: economic growth, population growth and inclusive human development. This study departs from the engaged contemporary literature which has largely focused on two factors: income and environmental degradation. On the other hand, this study argues that simply assessing the EKC hypothesis is not enough for policy-making initiatives. For instance, rejecting or confirming evidence of an EKC is less relevant to policy than establishing specific policy thresholds that policy makers can act upon to address concerns pertaining to environmental degradation. Accordingly, providing policy makers with a specific critical mass at which

[2]The EKC hypothesis postulates that in the long term, there is an inverted U-shaped relationship between per capita income and environmental degradation.

more economic growth or population growth is detrimental to the environment is more informative than simply confirming the existence or not, of an EKC. Moreover, in the light of the post-2015 development agenda which is particularly focused on inclusive human development, providing a specific human development critical mass that drives the green economy is more informative and relevant to policy makers. Therefore, the policy relevance of the study is in line with scholarly recommendations for a green revolution (Pingali, 2012).

While the theoretical underpinning of the EKC hypothesis has been substantially documented in the literature (Diao *et al*., 2009; Akbostanci *et al*., 2009; He & Richard, 2010), the theory-building contribution of this study relates to the establishment of specific thresholds at which macroeconomic outcomes can either positively or negatively influence environmental degradation. Hence, while this study builds on an established EKC hypothesis, it also advances knowledge within the perspective that it informs policy makers on thresholds pertaining to the EKC. The applied econometrics framework is consistent with the literature supporting the view that applied econometrics should not be exclusively limited to studies designed to either accept or reject existing theories and established hypotheses (Narayan *et al*., 2011; Asongu & Nwachukwu, 2016a).

The remainder of the study is organised as follows. The data and methodology are discussed in section 2 while the empirical results are covered in section 3. Section 4 concludes with implications and future research directions.

2. Data and methodology

2.1 Data

The study focuses on the 44 nations in the SSA region for the period 2000-2012[3] with data from three main sources, namely: (i) the World Development Indicators of the World Bank for the dependent variable (i.e. CO2 emissions), two independent variables of interest (i.e. economic growth and population growth) and a control variable (education quality); (ii) the

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[3]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".

World Governance Indicators of the World Bank for the control variable (i.e. regulatory quality) and (iii) the United Nations Development Programme (UNDP) for an independent variable of interest (i.e. the inequality-adjusted human development index). The geographical and temporal scopes of the study are contingent on data availability constraints at the time of the study.

The adopted CO2 emissions per capita variable, as a proxy for environmental degradation is in accordance with Asongu (2018a), while the use of the inequality-adjusted human development index (IHDI) to proxy for inclusive human development is consistent with recent inclusive human development literature in Africa (Asongu *et al.*, 2015; Asongu & Nwachukwu, 2017a). According to the underlying literature, the human development index (HDI) denotes the average of achievements in three main areas, namely: (i) basic standard of living, (ii) knowledge and (iii) health and long life. Furthermore, the IHDI is the human development (HDI) that is adjusted to the equitable distribution of the three main achievements. Hence, the IHDI is the HDI that has been adjusted for inequality.

In the light of the motivation of this study, the three economic development variables are: economic growth in the perspective to Gross Domestic Product (GDP) growth rate; the population growth rate and the IHDI discussed in the preceding paragraph. In order to limit issues pertaining to variable omission bias, two control variables are defined in the conditioning information set, namely: education quality and regulation quality. The control variables which are in line with recent CO2 emissions literature (Asongu, 2018b), are restricted to two because upon a pilot empirical investigation, it was apparent that focusing on more than two control variables generates concerns of instrument proliferation and over-identification. This procedure of adopting limited control variables in the generalized method of moments (GMM) approach (in order to avoid invalid models that do not pass post-estimation diagnostic tests) is not uncommon in the empirical literature. In essence, there is an abundant supply of GMM literature that has used limited control variables, notably: (i) zero control variable (Osabuohien & Efobi, 2013; Asongu & Nwachukwu, 2017b) and (ii) two control variables (Bruno *et al.*, 2012).

Concerning the anticipated signs, while both variables are expected to significantly influence the outcome variable, the expected effects on the dependent variable may also be contingent on the behavior of the data and other macroeconomic features. For instance, while regulation quality should naturally reduce CO2 emissions, the effectiveness of such regulation is contingent on the feasible implementation of adopted policies. It is worthwhile to emphasis that the regulation quality variable is negatively and positively skewed. Hence, an overwhelmingly negative skew can weigh unfavourably on the expected sign. The relevance of primary education in countries at initial levels of industrialisation is consistent with the attendant literature on the relative importance of this education level (i.e. compared to higher education levels) in development outcomes (Petrakis & Stamakis, 2002; Asiedu, 2014; Asongu & le Roux, 2017; Asongu & Odhiambo, 2018a).

2.2 Methodology

2.2.1 GMM: Specification, identification and exclusion restrictions

This study adopts the Generalised Method of Moments (GMM) approach to empirical investigation for four main reasons. First, a baseline requirement is that the number of cross sections should be higher than the corresponding number of periods in each cross section. This is the case in our study which is focusing on 44 countries with data points from 2000 to 2012. Therefore, the N (or 48) > T(or 13) primary condition is satisfied. Second, the environmental degradation variable is persistent given that the correlation between the level values and first difference (i.e. 0.9945) is higher than 0.800 which has been established to be the threshold for determining persistence (Tchamyou, 2019a, 2019b). Third, owing to the panel structure of the dataset, it is apparent that cross-country variations are taken into account in the estimations. Fourth, the concern of endogeneity is tackled from two main perspectives. On the one hand, reverse causality, or simultaneity, is addressed with the help of an instrumentation process. On the other hand, the unobserved heterogeneity is accounted for with the help of time-invariant variables.

The GMM strategy is the Roodman (2009a, 2009b) extension of Arellano and Bover (1995) which has been documented in contemporary literature to restrict instrument proliferation with an option that collapses instruments (Asongu & Nwachukwu, 2016b; Boateng *et al.*, 2018; Tchamyou *et al.*, 2019).

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

$$CO_{i,t} = \sigma_0 + \sigma_1 CO_{i,t-\tau} + \sigma_2 ED_{i,t} + \sigma_3 EDED_{i,t} + \sum_{h=1}^{2} \delta_h W_{h,i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t} \quad (1)$$

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

where, $CO_{i,t}$ is the carbon dioxide emission variableof country i in period t, σ_0 is a constant, ED entails economic development (GDP growth, population growth and inclusive development), $EDED$ denotes quadratic interactions between economic development indicators ("GDP growth" × "GDP growth", "population growth" × "population growth" and "inclusive development" × "inclusive development"), W is the vector of control variables (education quality and regulation quality), τ represents the coefficient of auto-regression which is one within the framework of this study because a year lag is enough to capture past information, ξ_t is the time-specific constant, η_i is the country-specific effect and $\varepsilon_{i,t}$ the error term.

2.2.2Identification and exclusion restrictions

We now devote space to clarifying identification properties and corresponding exclusion restrictions because they are paramount to a robust GMM specification. In accordance with the underlying literature (Asongu & Nwachukwu, 2016c; Tchamyou & Asongu, 2017; Tchamyou *et al.*, 2019; Boateng *et al.*, 2018), the time invariant variables adopted, are defined as strictly exogenous whereas all explanatory variables are acknowledged as "suspected endogenous" or predetermined. The intuition underlying this identification strategy is in accordance with Roodman (2009b) who has documented that it is not very probable for the suggested time invariant indicators to be first-differenced endogenous[4].

Given the discussed identification strategy, the exclusion restriction assumption is investigated by assessing if the identified strictly exogenous indicator affects CO2 emissions

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

exclusively via the suggested endogenous explaining variable mechanisms. The criterion used to assess the validity of this exclusion restriction is the Difference in Hansen Test (DHT). The null hypothesis of this test is the position that the identified strictly exogenous variable does not affect the CO2 emission variables beyond the engaged endogenous explaining variables. Hence, we expect the null hypothesis not to be rejected for the exclusion restriction assumption to hold. This expectation is consistent with the standard instrumental variable approach in which the rejection of the null hypothesis of the Sargan Overidentifying Restrictions (OIR) test indicates that the proposed instruments explain the outcome variable beyond the proposed channels or endogenous explaining mechanisms (Beck *et al.*, 2003; Asongu & Nwachukwu, 2016d).

3. Empirical results

3.1 Presentation of results

The empirical results are disclosed in Table 1. There are three main sets of specifications pertaining to each of the economic development variables. Each specific economic development variable is associated with three main specifications. From the left-hand to the right-hand side, the variables in the conditioning information set are increased. Accordingly, the first specification does not include a control variable; the middle specification entails a control variable while the last specification is associated with two control variables. In the light of the explanation in the data section, not involving control variables in the GMM specification is acceptable in the empirical literature. Hence, the step-wise approach of involving control variables can be tacitly considered as a robustness check procedure.

In the light of the identification strategy and corresponding discussion on exclusion restrictions in the preceding section, four main criteria are used to investigate the post-estimation validity of the GMM findings[5]. Building on these criteria, it is apparent that all estimated models pass the post-estimation diagnostic tests.

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[5] "*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*

In order to investigate the overall effect of increasing economic development on environmental degradation, net effects are computed in accordance with contemporary literature on the interactive (Tchamyou & Asongu, 2017; Tchamyou, 2019b; Agoba *et al.*, 2019) and quadratic (Asongu & Odhiambo, 2019) regressions. The corresponding net effects consist of both the unconditional effects and the marginal effects from the association interactions. For example in the third column of Table 1, the net effect of enhancing economic growth is -0.0040 (2×[0.0001× 4.801] + [-0.005]). In this calculation, the average value of economic growth is 4.801, the marginal effect of economic growth in CO2 emissions is 0.0001 while the unconditional effect of economic growth is -0.005. The leading 2 on the first term is from the differentiation of the quadratic term.

In the light of the same computational analogy, in the last column of the table, the net effect derived from enhancing inclusive human development is 0.2003 (2×[-2.133× 0.450] + [2.120]). In this calculation, the mean value of inclusive human development is 0.450, the unconditional effect is 2.120 while the marginal effect is -2.133. Accordingly, the leading 2 on the first term is from the differentiation of the quadratic term.

The following findings can be established from Table 1. The significant control variables have the expected signs. Enhancing economic growth and population growth both have net negative effects on CO2 emissions while enhancing inclusive human development has an overall net positive effect on the CO2 emissions. While from the perspective of net effect, the finding on inclusive human development is unanticipated, the corresponding negative marginal effect implies that increasing inclusive human development decreases the positive unconditional effect up to a certain threshold. Hence, the negative net effect can be neutralised at a specific threshold of inclusive human development. The attendant policy thresholds are established in the next section.

Hansen Test (DHT) for exogeneity of instruments is also employed to assess the validity of results from the Hansen OIR test. Fourth, a Fischer test for the joint validity of estimated coefficients is also provided" (Asongu & De Moor, 2017, p.200).

Table 1: Empirical results

	Dependent variable: CO2 emissions per capita								
	Economic Growth (EG)			Population Growth (PG)			Inclusive Human Development (IHDI)		
CO2 emissions (-1)	0.839***	0.917***	0.949***	0.893***	0.892***	0.888***	0.850***	0.974***	0.976***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Economic Growth (EG)	-0.0008	-0.005**	0.001	---	0.0007	-0.002*	---	---	0.0006
	(0.336)	(0.019)	(0.234)		(0.662)	(0.095)			(0.263)
Population Growth (PG)	---	-0.096***	0.007	-0.281***	-0.290***	-0.173***	---	0.022	0.027*
		(0.000)	(0.408)	(0.000)	(0.000)	(0.000)		(0.180)	(0.064)
IHDI	---	---	0.180	---	---	---	-2.429	2.308	2.120*
			(0.151)				(0.170)	(0.128)	(0.065)
EG ×EG	0.000005	0.0001*	-0.00005**	---	---	---	---	---	---
	(0.832)	(0.065)	(0.012)						
PG ×PG	---	---	---	0.038***	0.038***	0.028***	---	---	---
				(0.000)	(0.000)	(0.000)			
IHDI ×IHDI	---	---	---	---	---	---	3.176*	-1.951	-2.133*
							(0.077)	(0.238)	(0.084)
Education	---	-0.002	-0.0005	---	---	-0.002**	---	0.001	0.0006
		(0.218)	(0.460)			(0.018)		(0.285)	(0.466)
Regulation Quality	---	---	0.048***	---	---	0.219***	---	---	0.053
			(0.003)			(0.000)			(0.167)
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Net effects	na	-0.0040	na	-0.1025	-0.1125	-0.0422	na	na	0.2003
Thresholds	na	25	na	3.6973	3.8157	3.0892	na	na	0.4969
AR(1)	(0.113)	(0.135)	(0.016)	(0.147)	(0.148)	(0.148)	(0.039)	(0.010)	(0.012)
AR(2)	(0.294)	(0.226)	(0.251)	(0.777)	(0.758)	(0.151)	(0.134)	(0.195)	(0.240)
Sargan OIR	(0.046)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Hansen OIR	(0.498)	(0.295)	(0.599)	(0.106)	(0.207)	(0.367)	(0.179)	(0.768)	(0.766)
DHT for instruments									
(a)Instruments in levels									
H excluding group	---	(0.118)	(0.045)	---	---	(0.106)	---	(0.187)	(0.118)
Dif(null, H=exogenous)	(0.756)	(0.401)	(0.910)	---	(0.473)	(0.493)	(0.333)	(0.851)	(0.925)
(b) IV (years, eq(diff))									
H excluding group	---	---	(0.267)	---	---	(0.119)	---	---	(0.741)
Dif(null, H=exogenous)	---	(0.408)	(0.796)	---	---	(0.618)	---	(0.923)	(0.607)
Fisher	307.52***	14270.70 ***	1.15e+06 ***	4133.18 ***	4128.79 ***	15745.48 ***	2211.51 ***	18002.12 ***	69184.29 ***
Instruments	22	29	36	21	25	32	22	29	36
Countries	44	44	41	44	44	43	42	41	41
Observations	452	326	244	419	414	296	372	267	244

*, **, ***: 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, Hausman test 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 *OIR* test. na: not applicable because at least one estimated coefficient needed for the computation of net effects is not significant. The mean value of GDP growth, population growth and inclusive development are respectively, 4.801, 2.335 and 0.450. Constants are included in the regressions.

3.2 Extension with policy thresholds

In the light of the motivation and positioning of this study with respect to the extant literature (which is covered in the introduction), this section engages the policy thresholds and by extension, policy implications of the study. The computations of the thresholds are also substantiated with the attendant literature on thresholds that are relevant for more targeted policy implications.

Given the problem statement motivating this study, it is not enough to stop at establishing overall net effects on CO2 emissions from improving economic development. Hence, we move a step further by computing thresholds related to the marginal effects. For instance, the unconditional and conditional effects from increasing economic growth and population growth are respectively, negative and positive whereas the unconditional and conditional impacts from enhancing inclusive human development are respectively, positive and negative. Therefore, in the light of the attendant positive marginal effects from economic growth and population growth, an extended analysis can be made to assess at what specific thresholds or critical masses the positive marginal or conditional effects completely crowd-out the negative unconditional effects. It follows that at a specific economic development threshold, further increasing economic growth, or population growth, increases CO2 emissions. This is also translated as a U-shaped pattern. The narrative is the opposite for the relationship between inclusive human development and CO2 emissions: a Kuznets shape pattern.

It is also relevant to emphasise that the underlying thresholds are critical masses of economic development at which the net effect on CO2 emissions is completely nullified. However, in order for these thresholds to be economically relevant and make policy sense, they should be situated between the minimum and maximum values disclosed in the summary statistics. Hence, the policy relevance of the thresholds to be computed is contingent on whether policy actions with the established thresholds are feasible. This feasibility exclusively relies on whether the thresholds are consistent with the data underpinning the empirical exercise. This conception and definition of threshold conforms to the extant literature on the subject, notably: thresholds for favourable results that are relevant to policy makers (Batuo, 2015; Asongu & Odhiambo, 2018b; Asongu *et al.*, 2019); conditions for Kuznets and U shapes (Ashraf & Galor, 2013) and CO2 emission thresholds that are detrimental to inclusive development (Asongu, 2018a).

In Table 1, the positive threshold in the second column is 25 ($0.005/ [2\times0.0001]$). Hence, at 25% of GDP growth rate (i.e. annual %), GDP growth increases CO2 emissions, or is detrimental to a green economy. In the same vein, a population growth rate of above 3.089% (i.e. annual %) has a positive effect on CO2 emissions. Moreover, following the same analogy, an IHDI of 0.496 is the critical mass from which inclusive development decreases CO2 emissions. It follows that sampled countries should target an IHDI of above 0.496 in order to benefit from the relevance of the inclusive development in promoting the green economy.

The above thresholds have economic relevance and can be applied by policy makers because they are within the policy ranges disclosed in the summary statistics, notably:

"-32.832 to 33.735", "-1.081 to 6.576" and "0.219 to 0.768" for respectively, GDP growth, population growth and inclusive development.

4. Conclusion and future research directions

This study has investigated how increasing economic development affects the green economy in terms of CO_2 emissions, using data from 44 countries in the SSA region for the period 2000-2012. The Generalised Method of Moments (GMM) is used for the empirical analysis. The following main findings are established. First, enhancing economic growth and population growth both have net negative effects on CO_2 emissions while improving inclusive human development has an overall net positive effect on the CO_2 emissions. Second, there is a U-shape pattern between two indicators of economic development (i.e. economic growth and population growth) and CO_2 emissions, while there is a Kuznets nexus between inclusive human development and CO_2 emissions.

Third, when the analysis is extended to establish thresholds, the following findings are also established. (i) Increasing GDP growth beyond 25% of annual growth is unfavorable for a green economy; (ii) a population growth rate of above 3.089% (i.e. annual %) has a positive effect on CO_2 emissions and (iii) an inequality-adjusted human development index (IHDI) of above 0.496 is beneficial for a green economy because it is associated with a reduction in CO_2 emissions. The established critical masses have policy relevance because they are situated within the policy ranges of economic growth, population growth and inclusive human development.

It will be relevant to investigate whether the established linkages in this study can withstand empirical scrutiny when country-specific studies are involved. These country-specific cases are important because in the modelling of the GMM, country-specific impacts are eliminated by first differencing in order to avoid concerns of endogeneity.

Appendices

Appendix 1: Definitions of variables

Variables	Signs	Definitions of variables (Measurements)	Sources
CO_2 per capita	CO2mtpc	CO_2 emissions (metric tons per capita)	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)
Inclusive development	IHDI	Inequality-Adjusted Human Development Index	UNDP
Educational Quality	Educ	Pupil teacher ratio in Primary Education	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)

WDI: World Bank Development Indicators. UNDP: United Nations Development Program.

Appendix 2: Summary statistics (2000-2012)

	Mean	SD	Minimum	Maximum	Observations
CO_2 per capita	0.911	1.842	0.016	10.093	532
GDP growth	4.801	5.054	-32.832	33.735	530
Population growth	2.335	0.876	-1.081	6.576	495
Inclusive development	0.450	0.110	0.219	0.768	431
Educational Quality	43.892	14.775	12.466	100.236	397
Regulation Quality	-0.604	0.542	-2.110	0.983	496

S.D: Standard Deviation.

Appendix 3: Correlation matrix (uniform sample size: 283)

	CO2mtpc	GDPg	Popg	IHDI	Educ	RQ
CO2mtpc	1.000					
GDPg	0.011	1.000				
Popg	-0.574	0.208	1.000			
IHDI	0.640	-0.092	-0.611	1.000		
Educ	-0.449	0.106	0.363	-0.524	1.000	
RQ	0.401	-0.144	-0.279	0.536	-0.330	1.000

CO2mtpc: CO_2 emissions (metric tons per capita). GDPg: Gross Domestic Product growth. Popg: Population growth.
IHDI: Inequality-Adjusted Human Development. Educ: Education Quality. RQ: Regulation Quality.

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