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Examining the role of climate finance in the Environmental Kuznets Curve for Sub-Sahara African countries

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Abstract: The purpose of this study is to examine the impact of climate finance on pollutant emissions (CO_2, CH_4 and N2O) for a sample of 19 Sub-Sahara Africa (SSA) countries over the period 2006 to 2017. Our study augments the traditional Environmental Kuznets Curve (EKC) with climate finance and our findings affirm the existence of an inverted U-shaped relationship between per capita income and emissions (i.e. traditional EKC) as well as between climate finance and emissions (Climate finance-induced EKC). We particularly compute turning points of $3,690 ($CO_2$); $5,710 (CH4) and $6,420 (N2O) for per capita GDP levels and $910 million ($CO_2$), $1.2 billion (CH4) and $1. 6 billion (N2O) for climate finance funds. These turning points are above the current averages observed for the SSA countries hence

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PUBLIC INTEREST STATEMENT

Global warming is one of the greatest concerns of humans. Despite African countries not contributing much to climate change, these countries suffer the most from it as they do not have the proper means to mitigate and adapt to climate change. Therefore, industrialized economies who contribute the most to climate change have pledged climate funds to assist in less developed countries circumvent the adversities of climate change even though there is much debate on whether the current levels of climate assistance is enough for mitigation and adaptation purposes. Our study examines the effect of climate finance on greenhouse gas emissions for a sample of 43 African countries and we are particualry interested in computing the turning point at which climate fiannce begins to reduce carbon emissions. Our study shows that climate finance offered to most African countries have not yet reached that turning pointand and we therefore verify that climate finance received from African countries are not sufficient enough to address problems arising from climate change.

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implying that these African countries are not developed enough and neither receive sufficient climate funding to address the challenges arising from climate change.

Subjects: Economics; Econometrics; Environmental Economics

Keywords: Environmental Kuznets Curve (EKC); Carbon emissions (CO_2); methane emissions (CH4); nitrous oxide emissions (N2O); climate finance; pollution haven-halo hypotheses

1. Background

Sustainable Development Goal 11 is aimed at making cities inclusive, resilient, safe and sustainable. To achieve this goal, the world must undertake concerted effort to reduce greenhouse gas (GHG) emissions and increasingly rely on "clean" energy sources. Over the past decade, GHG emissions have been on a rise at a rate of 1.5 per cent per annum, even though they stabilized briefly between 2014 and 2016 due to reductions in China's emission levels (Christensen & Olhoff, 2019). However, since 2016 total GHG emissions have continued to rise, reaching a record high of 55.3 $GtCO_22$ in 2018 , although the most recent COVID-19 pandemic has slowed GHG emissions in 2020. As of May 2020, the world lost approximately US$2.1 trillion in income and global emissions reduced by 2.5Gt of total GHG with a loss of 5.1Mt of nitrous oxide (N2O) due to COVID pandemic (Helm, 2020; Lenzen et al., 2020). Moreover, following the shift in political landscape resulting from the most recent US presidential elections, global efforts to reduce environmental degradation are bound to take it's deserving priority.

Since the early 2000s Sub-Sahara African (SSA) countries have experienced rapid levels of economic growth although this has resulted in higher demand for energy and heavier reliance on fossil fuel which have heightened environmental pollution from greenhouse gas (GHG) emissions (Huisingh et al., 2015; Nazeer et al., 2016; Bekhet & Othman, 2017;; Zaman & Abd-el Moemen, 2017). According the theoretical dynamics of the Environmental Kuznets Curve (EKC) first presented by Grossman and Krueger (1995), at initial stages of development, higher economic growth is accompanied with higher environmental degradation, but after crossing a certain "threshold" level of development, higher growth rates are accompanied with lower environmental degradation as economies adopt more environmental-friendly technologies. This relationship is envisioned as an inverted U-shaped curve between environmental degradation and economic activity. However, there is much concern amongst policy makers and researchers alike, who argue that reduction in environmental degradation will not come automatically with higher economic development; and hence policies must be formed and geared toward emission reduction.

To limit the catastrophic effects of climate change on the world, the Intergovernment Panel on Climate Change (IPCC, 2014) intimated the need to reduce global warming to 2°C and maintain an atmospheric concentration which does not exceed 450 ppm CO_2. Friedl and Getzner (2003) postulated that to achieve these targets in a world that will support a population of 9.2 billion by 2050, the annual global average per capita emission needs to reduce to between 2.1 to 2.6 tonnes CO_2. Up-to-date, SSA countries have contributed the least to global carbon emissions, and yet the region suffers the most from the adverse effects of environmental degradation.

For this cause developed countries have pledged funds to support developing countries in adopting technologies and practices to achieve sustainable development in a carbon constrained world (Ryan et al., 2015). Dating back to the 2009 Copenhagen Accord, industrialized nations committed to providing new and additional resources approximated at US$30 billion between 2010 and 2012, and to further raise US$100 billion per year by 2020 from a wide range of funding sources. The focus of climate finance has been on reducing carbon emission from fossil fuel-intensive industries; including iron and steel, chemicals and petrochemicals, and cement companies (Warren, 2020).

Our study examines the emission reduction ability of climate finance received by SSA; and particularly tests whether the effect of climate finance on carbon emission follows the theoretical dictates of EKC. This is reminiscent of the pollution haven-halo hypotheses which depict that foreign direct investment (FDI) to developing economies harm environmental degradation as emissions are transferred away from industrialized economies to developing countries, whilst at later stages of development FDI results in higher usage of environmentally friendly technology hence reducing emissions (Balsalobre-Lorente et al., 2019). We consider climate finance as a blend of FDI and development aid (distinguishable from the former in that profit-maximization is not the main objective and distinguishable from latter in that it focused on providing direct investment against climate change) which are used to finance projects specifically geared towards mitigating and adopting solutions to climate change in developing countries. We hypothesize that at lower levels of financing, climate funds may insignificantly contribute towards reducing environmental degradation but at higher levels of climate finance this would begin to significantly contribute towards a cleaner environment. We test the resulting climate-finance induced EKC on three main categories of GHG, namely; carbon dioxide (CO_2) emissions, methane (CH_4) emissions and nitrous oxide (N2O) emissions. Our study is consequentially able to identify different "climate finance" turning points for the different types of GHG emissions which, to the best of our knowledge, is the first study to do so.

The remainder of this manuscript is organized as follows. The next section of the study presents a review of the associated literature. Section 3 presents the empirical data and model used in the study. The findings of the study are presented in Section 4 whilst the study is concluded in Section 6.

2. Literature review

Our study is related to two strands of empirical literature, namely i) the literature on the EKC in context of GHG emissions (i.e. carbon emissions (CO_2), sulfur emissions (CH4) and methane emissions (N2O)) ii) the literature on the relationship between environmental degradation and FDI (Pollution haven and pollution halo hypotheses). These are discussed separately in the following subsections.

2.1. EKC and GHG emissions

The relationship between GHG emissions and environmental degradation can be further disaggregated into three sub-topics i) the literature on carbon-induced EKC ii) the literature on sulfur-induced EKC iii) the literature on methane-induced EKC. A brief overview of these GHG emissions as well as their associated literature in context of EKC are discussed in this section.

CO_2 has constituted more than two-thirds of global GHG and hence most countries have focused on CO_2 reduction as compared to pollutant emissions (; Murshed & Dao, 2020). Notably, a majority of climate funds geared towards developing countries to mitigate and adapt to climate change has been spent on CO_2 emission reduction (Buchner et al., 2019). It is therefore not surprising that most prior studies testing the EKC were conducted for CO_2 emissions and most studies conducted for African countries affirmed the existence of EKC (Kivyiro & Arminen, 2014; Osabuohein et al., 2014; Al-Mulali & Ozturk, 2016; Shahbaz et al., 2019; Inglesi-Lotz & Dogan, 2018; Hanif, 2018; Sarkodie and Adams, 2018; Ssali et al., 2019; Beyene & Kotosz, 2019; Adedoyin et al., 2020; Egbetokun et al., 2020; Opoku & Boachie, 2020; Alsayed & Malik, 2020). Only a few studies did not lend their support to the CO_2-induced EKC in Africa (Shahbaz and Sinha, 2019; Yusuf et al., 2020).

N_2O emissions contributes approximately 7 percent to total GHG globally . Its emission occurs during fossil fuel combustion, industrial and agricultural activities, and solid and liquid waste management. N_2O contributes to global warming 300 times that of carbon dioxide and stays in the air for an average of 114 years (IPCC, 2014; Miah et al., 2010; United States (US) Environmental Protection Agency (EPA), 2018). In the fight against climate change, N_2O has received very little attention worldwide as 74 percent of N_2O emission is from fertilized soil and animal waste and is thus an intricate part of agriculture production. Therefore, N_2O emissions present a food related dilemma, the more we try reducing it the hungrier the world becomes. Nevertheless, the devastating effect of N_2

O emissions on human health cannot be overemphasized; these include, amongst others, emphysema, bronchitis and damaged lung tissues (Mania, 2020).

Notably, only a handful of studies have tried examining the EKC in the context of N_2O emissions. Nevertheless, most of the studies conducted on the relationship between N_2O emissions and economic growth affirmed the existence of EKC (Selden & Song, 1994; Magnani, 2001; Mania, 2020; ; Fujii & Managi, 2016; Sarkodie & Strezov, 2019; Opoku & Boachie, 2020; Haider et al., 2020), with a few contrary viewpoints (Roca et al., 2001; Sinha et al., 2019; Egbetokun et al., 2020; Yusuf et al., 2020). We find very little literature existing for African economies as a panel sample.

CH_4 is the second largest contributor to total GHG behind CO_2 and contributes 10 percent of total GHG (US EPA, 2018). CH_4 emissions arise during the production and transportation of coal, oil and gas. At times CH_4 emissions arise due to agricultural and livestock practices-mainly from cow dungs and belching, decay of municipal solid waste, landfills and organic waste decay. Borunda (2019) notes that CH_4 emissions is 28 times more powerful than CO_2 at warming the earth. The literature on EKC for CH_4 emissions is very limited and produces conflicting results. Roca et al. (2001) and Fujii and Managi (2016) did not support the EKC for CH_4 emissions; whereas Opoku and Boachie (2020) and Yusuf et al. (2020) found support for EKC for CH_4 emissions. We fail to find any literature investigating the EKC for CH_4-induced EKC for SSA countries.

2.2. FDI and environmental degradation

The relationship between FDI and environmental degradation is embedded in two theories; the pollution haven hypothesis and the pollution halo hypothesis, both which are closely related with EKC.

On one hand, the pollution haven hypothesis speculates that industrialized economies, with stricter environmental regulations, seek to transfer dirty energy emissions to less industrialized economies how have "relaxed" environmental regulations. Therefore, as investment flows from developed to developing economies, this will lower environmental degradation in industrialized economies whilst increasing emission in the host countries. Notably, a few studies have confirmed the pollution haven hypothesis; Behera and Dash (2017) showed a significant positive effect of energy consumption and FDI on carbon emissions for 17 South East Asian (ASEAN) countries. Sarkodie and Strezov (2019) found a strong positive and significant impact of energy consumption on greenhouse gas emissions in affirmation of the pollution haven hypothesis for all five countries in their panel (China, India, Iran, Indonesia and South Africa).

On the other hand, the pollution halo hypothesis speculates that as increasing FDI is flowing into less developed economies, low-carbon technologies are introduced by investors to reduce GHG emissions or investors focus much on the services industry instead of the industrial sector, hence decreasing GHG emissions. For instance, Zhu et al. (2016) found a significant negative impact of FDI on CO2 for ASEAN nations, including Indonesia, Malaysia, Philippines, Singapore and Thailand, lending credence to the pollution halo effect as opposed to the pollution haven hypothesis. Moreover, Gharnit et al. (2019) provide evidence of a positive effect of FDI on environmental degradation in 54 African countries whilst Mert and Calgar (2020) find that FDI reduces CO_2 emissions in Turkey. Conversely, Tenaw (2020) more recently finds no effect of FDI on environmental degradation for 20 of African's top FDI recipients. Zugrabu-Soilita (2017) confirm the pollution haven hypothesis holds for countries with high capital endowments and relaxed environmental regulations whilst the pollution halo hypothesis holds for countries with low capital endowments and stricter regulations. In attempts reconcile the pollution haven and pollution halo hypothesis, a study by Balsalobre-Lorente et al. (2019) finds a nonlinear, inverted notably, muchU-shaped relationship between FDI and environmental degradation, in the spirit of the traditional EKC. Our study extends on this previous literature by envisioning climate finance as

a form of foreign investment in the fight against environmental degradation and tests the validity of a climate finance-induced EKC for SSA countries.

3. Data and methodology

3.1. Data

For the analysis, data was collected from 2006 to 2017 for 19 countries in SSA, and our sample choice is dictated by data availability, particularly for climate finance. Our sample consists of Angola, Benin, Botswana, Cameroon, Congo (Brazzaville), Congo (DRC), Ethiopia, Gabon, Ghana, Kenya, Mauritius, Mozambique, Namibia, Niger, Nigeria, Senegal, South Africa, Sudan, Tanzania and Togo. We employ nine time series variables in our study, namely; carbon emission (CO_2), methane emission (CH4), nitrous oxide emission (N2O), climate finance (CF), per capita GDP (GDPP), energy consumption (ENC), governance readiness (GR), renewable energy use (REN), foreign direct investment (FDI) and urbanization (URB).

All the pollutant emissions variables collected were measured in units of million metric tons of carbon dioxide equivalent ($MtCO_2$); and are sourced from the climate analysis indicators tool (CAIT). CF is the total amount in millions of dollars of climate related aid finance flows from developed countries to the SSA countries and is sourced from OECD Development Assistance Committee's (DAC's) climate-related aid (CRA) statistics. GDPPC data is the per capita income in US dollars; ENC measures the energy use of a country in kg of oil equivalent per capita; REN is the share of renewable energy in total final energy consumption; URB is the percentage of the population living in urban areas; FDI is the inward receipt of foreign investment which represents foreign ownership of productive assets. FDI and CF may overlap as some FDI is classified as "green FDI" but this type of FDI is commonly operate outside a carbon market context. Data on GDPPC, FDI, URB, REN and ENC are sourced from the World Development Indicators. GR is an indexed measure of control of corruption, regulatory quality and rule of law and the series are sourced from the Notre-Dame Global Adaptation Index (ND-GAIN). All data analysis of this study was carried out using STATA 13.

The summary statistics for the variables are reported in Table 1. Note that the GHG variables serve as dependent variables of the study: CO_2, CH_4, N_2OE. We observe that CO_2 on average is $71MtCO_2$ with very high level of dispersion of 441.91. South Africa was found to have on average the highest CO_2 ($441.91MtCO_2$) and Congo having the least (37.156). Nigeria and Cameroon have proven to be the SSA countries with the highest CH4 ($33MtCO_2$) and N20E ($63MtCO_2$) respectively. Gabon was least in in CO_2 ($-88MtCO_2$) and total GHG ($-85MtCO_2$ 5); whereas Mauritius was lowest in N_2OE and total GHG.

Explanatory variables of the study consist of CF, ENC, GR, URB, REN, FDI and GDPP. We find Kenya to be the country to get the largest CF in a single year, followed by South Africa; whereas Benin had the least CF in the sub-region within the study period. Results from the summary statistics show that Gabon (3098) is the largest consumer of energy in SSA with Niger being the least consumer (113). GDP per capita was computed by dividing GDP at constant 2010 US$ by the population of the country. On the average GDPPC of SSA for the study period averaged $2869, which corresponds to a category of lower middle-income sub-region with high dispersion of $2820. Gabon was found to have the highest GDP per capita for the study period of $10,716.

Furthermore, the pairwise correlation matrix of the time series is presented in Table 2 to provide preliminary evidence on the co-movement between the time series variables. We note positive estimates for the correlations between FDI, climate finance and all classes of emissions, hence providing preliminary evidence in support of the pollution haven effect. On the other hand, government readiness is the only variable which exerts a negative correlation with all classes of GHG emissions. The remaining correlations vary amongst the different emissions with per capita GDP

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Table 1. Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CO_2	209	71.27789	113.6304	−88.2	441.91
CH4	209	30.43512	31.37251	1.18	133.82
N20	209	16.17904	16.45962	.22	63.7
GDPPC	213	2869.762	2820.513	193.7949	10,716.2
CF	213	510.3185	523.7081	2.186	2656.563
ENC	171	735.1684	710.1128	113.4227	3098.422
REN	190	61.47394	25.32268	10.63386	94.94233
URB	213	44.37691	17.32537	15.899	88.559
FDI	213	1.40e+09	2.15e+09	−7.12e+09	1.00e+10
GR	213	.4136833	.1257331	.1762142	.6685993

and urbanization being positively correlated with CO_2 and negatively correlated with CH_4 and N_2O whilst renewable energy is negatively correlated with CO_2 and positively correlated with CH_4 and N_2O.

3.2. Model and estimation technique

This study seeks to re-assess the EKC hypothesis for the SSA region by examining the impact of CF and economic activity on GHG in SSA. To this end we specify the following three reduced form EKC models for CO_2, CH_4, N_2O, respectively:

$$CO2_{it} = \delta_1 + \delta_2 GDPPC_{it} + \delta_3 GDPPC_{it}^2 + \delta_4 CF_{it} + \delta_5 CF_{it}^2 + \delta_6 EnC_{it} + \delta_7 GR_{it} + \delta_8 URB_{it} + \delta_9 FDI_{it} + \delta_{10} REN_{it} + \mu_{it} \quad (1)$$

$$CH4E_{it} = \delta_1 + \delta_2 GDPPC_{it} + \delta_3 GDPPC_{it}^2 + \delta_4 CF_{it} + \delta_5 CF_{it}^2 + \delta_6 EnC_{it} + \delta_7 GR_{it} + \delta_8 URB_{it} + \delta_9 FDI_{it} + \delta_{10} REN_{it} + \mu_{it} \quad (2)$$

$$N2O_{it} = \delta_1 + \delta_2 GDP_{it} + \delta_3 GDPPC_{it}^2 + \delta_4 CF_{it} + \delta_5 CF_{it}^2 + \delta_6 EnC_{it} + \delta_7 GR_{it} + \delta_8 URB_{it} + \delta_9 FDI_{it} + \delta_{10} REN_{it} + \mu_{it} \quad (3)$$

Where i = 1, …, N captures the cross-sectional dimension of the regression, and t = 1, …, T captures the time dimension, δ_1 is the regression intercept, $\delta_2, \delta_{,3}, \delta_4, \delta_5, \delta_6, \delta_7, \delta_8, \delta_9 and \delta_{10}$represent the coefficients of the predictor variables under study. $\mu_{it} = {}'_i + {}_t + \varepsilon_{it}$ where μ_{it} represents the error term,$_i$ represents individual country effect, $_t$ represents time specific effect and ε_{it}= represents random disturbance term. Squared term of GDPPC and CF are added to induce asymmetries in the model and allow us to estimate the turning points in the regression. Note that traditional EKC is verified if δ_2>0 and δ_3<0, whilst the climate finance-induced EKC is verified if δ_4>0 and δ_5<0. The per capita income turning point of the inverted U curve is computed as,—$\frac{\delta_2}{2\delta_3}$; and the climate finance turning point is —$\frac{\delta_4}{2\delta_5}$. We further expect energy consumption to produce a positive impact on emissions (i.e. δ_6 > 0), government readiness, urbanization and renewable energy to lower emissions (i.e. $\delta_7, \delta_8, \delta_{10}$ > 0), whereas FDI can be either impact emissions positively ((i.e. δ_9>0) or negatively (i.e. δ_9<0).

A major setback of panel data settings is the existence of cross-sectional dependence amongst the time series, resulting in inconsistent estimates (Özokcu & Özdemir, 2017; Sarkodie & Strezov, 2019). To circumvent this problem, the Driscoll and Kraay (1998) algorithm is employed which

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Table 2. Pairwise correlation

	CO_2	CH4	N20	GDPPC	CF	REN	URB	FDI	GR
CO_2	1.0000								
CH4	0.5790	1.0000							
N20E	0.4425	0.6103	1.0000						
GDPPC	0.0758	−0.2324	−0.3229	1.0000					
CF	0.2652	0.5411	0.4182	−0.3585	1.0000				
REN	−0.0932	0.3930	0.4277	−0.5848	0.3611	1.0000			
URB	0.1184	−0.3035	−0.2305	0.6893	−0.4560	−0.3620	1.0000		
FDI	0.5603	0.4220	0.1574	0.0220	0.2989	0.0102	0.0813	1.0000	
GR	−0.0672	−0.4825	−0.4704	0.5435	−0.2420	−0.7105	0.2190	−0.0960	1.0000

accounts for cross-sectional dependence; yielding consistent and robust estimated standard errors. Secondly, the Driscoll-Kraay algorithm assumes that error structure is heteroskedastic and autocorrelated to some lag length (Sarkodie & Strezov, 2019). Furthermore, Driscoll-Kraay (DK) estimator is nonparametric and flexible without many restrictions imposed on the limiting behaviour of the number of panels. Another estimator that effectively deals with heteroskedasticity and autocorrelation is the feasible generalized least squares (FGLS) which will also employ in our study to enhance the robustness of the results. In addition to the D-K and FGLS estimators, we further employ the panel quantile regression as an additional sensitivity analysis.

4. Empirical analysis

4.1. Stationarity tests

Most time series variables have been found to exhibit non-stationary characteristic, which when not differenced poses some challenges to estimations. We apply the IPS and ADF-Fisher panel unit root tests to check whether the variables employed in this study are stationary at I(0) or first difference stationary I(1). Both tests are performed with a intercept and a trend and intercept and the results are reported in Table 3. From the results, we observe that in their levels, the time series are not mutually stationary process whilst all the time series variables are mutually stationary in their first differences.

4.2. Cointegration tests

In order to establish whether a long run cointegration relationship exists between CF, GDPP and the various GHG variables, we employ Pedroni residual cointegration test; which contains seven statistics to find out whether cointegration or long run relationship exists among the variables. The results of the cointegration tests are reported in Table 4. From the results, at least half of the report statistics confirm cointegration for our three specified regressions, regardless of whether we are examining for "within-dimension" or "between-dimension" cointegration. We treat these results as sufficient evidence for the existence long run cointegration within the regressions.

4.3. Main regression results

This section of the paper presents the main empirical regressions results from our econometric analysis. The findings from the panel regression with Driscoll-Kraay standard errors and the FGLS estimates are presented in Table 5 and, for convenience sake, can be summarized in three points.

Firstly, we note that in all estimated regressions, the economic activity-induced EKC and the climate-finance-induced EKC are verified. On one hand, at low levels of economic activity (climate finance) there is positive and statistically significant correlations with all classes of GHG emissions. On the other hand, at higher levels of economic activity (climate finance), after

Table 3. Panel unit root test results

Levels			First differences		
VARIABLES	**IPS**	**ADF-Fisher**	**VARIABLES**	**IPS**	**ADF-Fisher**
C2OE	1.2155	0.1191	**ΔC2OE**	−5.6868	−15.3115
	(0.8879)	(0.5473)		(0.0000)***	(0.0000)***
N2O	−1.6906	−5.9959	**ΔN2O**	−6.8142	−29.7110
	(0.0455)*	(0.0000)***		(0.0000)***	(0.0000)***
CH4	1.9663	−1.2165	**ΔCH4**	−5.5232	−22.4185
	(0.9754)	(0.1133)		(0.0000)***	(0.0000)***
GDPP	−1.1706	−1.3708	**ΔGDPP**	−4.6039	−7.3389
	(0.1209)	(0.0868)*		(0.0000)***	(0.0000)***
CF	−2.9999	−4.9656	**ΔCF**	−6.8942	−25.6040
	(0.0014)***	(0.0000)***		(0.0000)***	(0.0000)***
ENC	2.3303	2.4170	**ΔENC**	−3.3907	−7.3260
	(0.9901)	(0.9913)		(0.0003)***	(0.0000)***
GR	−0.3752	−0.8870	**GR**	−5.3392	−13.4787
	(0.3538)	(0.1886)		(0.0000)***	(0.0000)***
REN	−0.3115	−3.0155	**ΔREN**	−4.0634	−11.6887
	(0.3777)	(0.0016)***		(0.0000)***	(0.0000)***
URB	10.3633	−23.4603	**ΔURB**	−3.4789	−5.4943
	(1.0000)	(0.0000)***		(0.9997)	(0.0000)***
FDI	−2.4129	−5.5514	**ΔFDI**	−5.2466	−14.6041
	(0.0079)***	(0.0000)***		(0.0000)***	(0.0000)***

Notes: "***", "**", "*" denote the 1%, 5% and 10%, significance levels, respectively.

a certain threshold is crossed, the relationship turns negative and statistically significant albeit this positive effect being minute. The observed support for the traditional EKC is comparable to the previous studies of Kivyiro and Arminen (2014); Osabuohein et al. (2014); Al-Mulali and Ozturk (2016); Shahbbaz et al. (2016); Inglesi-Lotz and Dogan (2018); Hanif (2018); Sarkodie & Adams (2018); Ssali et al. (2019); Beyene and Kotosz (2019); Adedoyin et al. (2020); Egbetokun et al. (2020); Opoku and Boachie (2020); Alsayed & Malik (2020) for African samples. However, we note that the support for the climate-finance EKC is novel evidence in the empirical literature.

Secondly, the turning points obtained for economic activity and climate finance, differ for difference classes of GHG emissions. In general, we observe the lowest turning points for CO_2 emissions, followed N_2O emissions whilst CH_4 produces the highest turning points. These observations hold for both economic activity and climate finance, turning points and across both estimators. The computed turning points are \$3,690 (CO_2); \$5,710 (CH_4) and \$6,420 (N_2O) for per capita GDP levels and \$910 million (CO_2), \$1.2 billion (CH_4) and \$1.6 billion (N_2O) for climate finance funds.

Lastly, the remaining control variables generally produce their expected signs. On one hand, negative and significant estimates are found for government readiness and urbanization across all classes of GHG emissions. These findings are comparable to those found in Zhang et al. (2015), Kasman and Duman (2015), Mehdi (2016), Abdallh & Abugamos (2017) and Azam et al. (2021). On the other hand, positive and statistically significant estimates are found for energy consumption (i.e. CO_2), FDI (i.e. CH_4 and N_2O) and renewable energy (i.e. CO_2 and CH_4). Note that whilst the coefficient positive estimates on energy consumption and FDI (i.e. pollution halo effect) are expected and are consistent with findings in the empirical literature (e.g., Behera & Dash, 2017; Sarkodie & Strezov, 2019; Balsalobre-Lorente et al., 2020), the positive estimate on renewable energy is quite surprising

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Table 4. Pedroni residual cointegration test

	CO_2	CH4	N2O
Panel A: Common AR Coefficients (Within-Dimension)			
Panel v-statistics	0.6403	−0.1065	−0.01862
Panel rho-statistics	3.683***	−0.3536	−0.0273
Panel PP-statistics	−3.322***	−3.188***	−4.635***
Panel ADF-statistics	−2.111***	−1.556	−2.121***
Panel B: Individual AR Coefficients (Between-Dimension)			
Group rho-statistics	5.38***	1.521	1.179
Group PP-statistics	−4.633***	−3.366***	−7.478***
Group ADF-statistics	−3.142***	1.321	−1.939***

Notes: "***", "**", "*" denote the 1%, 5% and 10%, significance levels, respectively

since, a number of authors inclusive of Adams and Acheampong (2019) and Koengkan et al. (2019) find that renewable energy reduces environmental degradation. However, our findings of a positive effect of renewable energy on emissions has been recently found in the study of Adams and Nsaih (2019) who argues that renewable energy can contribute to increased emissions if countries have low levels of democracy and institutions.

4.4. Panel quantile regression

As part of our sensitivity analysis we follow the studies of Flores et al. (2014) and Allard et al. (2018) and provide panel quantile regression estimates to control for distributional heterogeneity. The panel quantile regressions allow for the estimation of the conditional mean function on a full range of conditional quantile "points" hence providing a more complete picture relationship between the dependent and independent variables We model the conditional mean function of the greenhouse emission (GHG) on it's set of conditioning variables (X) which can be expressed as:

$$\min_{\beta}[\theta\sum^{|} GHG_t - X_t\beta\Big|+(1+\theta)\sum^{|} GHG_t - X_t\beta\Big|]\{t: GHG_t \geq X_t\beta\}\{t: GHG_t<X_t\beta\} \tag{4}$$

Where, $\{GHG, t = 1, 2\ldots, T\}$ is a random sample on the regression process. $GHG{=}_t + X_t\beta$, with conditional distribution function of $F_{GHG_{/X}}(y) = F(GHG_t \leq inv) = F(GHG_t - X_t\beta)$ and $\{X_t, t = 1, 2\ldots, T\}$ is the sequences of (row) k-vectors of a known design matrix. The θth regression quantile, $Q_{GHG_{/X}}(\theta), 0<\theta<1$ is any solution to minimize problems. Consequently, β_θ denotes the solution from which the θth conditional quantile$Q_{GHG_{/X}}(\theta) = x\beta_\theta$. In our study we focus on 3 "quantiles" within the regression, that is, the 25th, 50th and 75th quantiles, which are designated as our lower, middle and upper regimes of the independent variables within the quantile regression. The empirical estimates of the quantile regressions for the different categories of GHG emissions are presented in Table 6.

Our results show that, on one hand, the traditional EKC significantly holds at the 50th and 75th quantiles for both CO_2 emissions (Panel A) and CO_20 emissions (Panel C) whilst being significant at the 25th and 50th quantiles for CH4 (Panel B). On the other hand, the climate finance-induced EKC significantly holds at all quantile distributions for CO_2 emissions (Panel A), but is only significant at

Table 5. Panel regression results

	DRISCOLL-KRAAY STANDARD ERRORS			FGLS		
VARIABLES	**CO_2**	**CH4**	**N2O**	**CO_2**	**CH4**	**N2O**
GDPP	0.0452***	0.0239***	0.00710***	0.0452***	0.0239***	0.00710***
	(0.00763)	(0.00163)	(0.000821)	(0.0108)	(0.00267)	(0.00197)
$GDPP^2$	−5.70e-06***	−1.86e-06***	−6.22e-07***	−5.70e-06***	−1.86e-06***	−6.22e-07***
	(4.37e-07)	(9.42e-08)	(1.02e-07)	(1.00e-06)	(2.48e-07)	(1.83e-07)
CF	0.213***	0.0485***	0.0333***	0.213***	0.0485***	0.0333***
	(0.0399)	(0.00437)	(0.00529)	(0.0408)	(0.0101)	(0.00744)
CF^2	−0.00012***	−2.01e-05***	−1.43e-05***	−0.00012***	−2.01e-05***	−1.43e-05***
	(1.57e-05)	(1.96e-06)	(2.46e-06)	(2.24e-05)	(5.53e-06)	(4.07e-06)
ENC	0.0951***	0.00137	−0.000761	0.0951***	0.00137	−0.000761
	(0.0119)	(0.00261)	(0.00117)	(0.0150)	(0.00370)	(0.00273)
GR	−150.3***	−97.11***	−35.48***	−150.3**	−97.11***	−35.48***
	(35.48)	(5.325)	(3.055)	(65.94)	(16.30)	(12.01)
RE	−0.404	0.438***	0.196***	−0.404	0.438***	0.196***
	(0.244)	(0.0559)	(0.0218)	(0.395)	(0.0975)	(0.0719)
URB	−1.109***	−0.957***	−0.0976***	−1.109**	−0.957***	−0.0976
	(0.304)	(0.0438)	(0.0278)	(0.543)	(0.134)	(0.0989)
FDI	1.32e-08**	2.73e-09*	−4.87e-10	1.32e-08***	2.73e-09***	−4.87e-10
	(4.08e-09)	(1.29e-09)	(4.13e-10)	(2.99e-09)	(7.40e-10)	(5.45e-10)
Constant	33.18	28.16**	4.573	33.18	28.16**	4.573
	(27.27)	(9.407)	(5.049)	(55.55)	(13.73)	(10.12)
GDPP TP	**$3,960**	**$6,420**	**$5,710**	**$3,960**	**$6,420**	**$5,710**
CF TP	**$910,000,000**	**1,210,000,000**	**$1,600,000,000**	**$910,000,000**	**$1,210,000,000**	**$1,600,000,000**
Observations	171	171	171	171	171	171
R-squared	0.625	0.683	0.397			
Wald (*p-value*)	0.0000	0.0000	0.0000			

*Notes: TP represents the turning point. Standard errors in parentheses *** p < 0.01, ** p < 0.05, * p < 0.1*

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the 25th quantile for CH_4 emissions (Panel B) and at the 25th and 75th quantiles for CO_2O emissions (Panel C). We also observe that the estimated turning points increase as one transverses from lower to higher quantiles which is a finding similar to that found in the previous studies of Flores et al. (2014) and Allard et al. (2018). However, our estimates reveal per capita incomes turning points ranging from $3205 to $6234 for CO_2, $5820 to $9652 for CH_4 and $6306 to $7167 for N_2O as well as climate finance turning points ranging from $812 million to $894 million for CO_2, $1.10 billion to $1.36 billion for CH_4 and $1.18 billion to $2.64 billion. These findings are similar to those obtained from our baseline regressions in that CO_2 still have the lowest turning points for both per capita income and climate finance, and this is followed by turning points for CH_4 and CO_2.

We also note weak evidence of the pollution haven effect as significant and positive estimates on the FDI coefficient are only significant at the 25th quantile for CO_2 emissions (Panel A) and at the 75th quantile for N2O emissions (Panel C). The urbanization variable produces insignificant estimates at all quantile for CO_2 emissions and its expected negative and significant estimates at all quantiles for CH4 and N2O emissions whilst government readiness is produces its expected negative and significant estimates at the 25th quantile for CO_2, 25th and 50th quantiles for CH4 and at all quantile for N2O. Lastly, energy consumption produces its expected positive and significant estimates at all quantile levels for CO_2, at 50th quantile for CH4 and is insignificant at all quantiles for N2O whereas renewable energy produces statistically significant positive estimates at 50th and 75th quantiles for CO_2 and N2O emissions, and at all quantile distributions for CH4. All-in-all, the findings obtained from the quantile estimates are in sync with those obtained in our baseline analysis.

5. Conclusion

Over the last two decades, many industrialized countries have pledged "climate funds" towards mitigation and adaptation solutions to climate change in developing countries. Our study examines the role which climate finance plays in reducing pollutant emissions (i.e. CO_2; CH4; N2O) in African recipient countries. To do so, we augment the traditional EKC with climate finance and estimate turning points for per capita income and climate funds for a panel of 19 SSA countries between 2006–2017. We summarize the study's findings and policy implications as follows.

Firstly, our estimated regressions reveal the existence of the traditional EKC in SSA for all the disaggregated GHG variables, even though the turning points occurs at different levels of per capita income. We find decarbonization begins beyond income levels of $3,690 for CO_2 emissions; $5,710 for CH4 emissions and $6,420 for N2O emissions. Notably, the estimated turning points are above the current per capita income levels of our sample of SSA countries hence implying that these countries are still in their initial developmental stages; in which they heavily rely on environmental unfriendly production activities, such as natural resource mining and intensified agricultural activities. It is only after crossing the identified per capita income "turning points", can African countries have sufficient development in order to adopt clean-energy technologies and enforce stricter environmental conservation rules.

Secondly, we find a similar inverted U-shaped relationship between climate finance and environmental degradation with different estimated turning points of $910 million for CO_2, $1.2 billion for CH4 and $1. 6 billion for N2O. We interpret these results to imply that climate finance does not reduce GHG in the initial stages since much of the funds are spent on research and development, and looking for innovative ways to mitigate and adapt to climate change. Parts of the initial funds are also spent on advocacy and raising awareness. Note that these financing activities form the core thematic pillars of the African Climate Change Strategy which many African countries have adopted and implemented as blueprint to combatting climate change since 2014. For instance, in 2019, the World Bank has pledged $60 million to African countries to advance research on climate change to strengthen the resilience of the Agriculture sector. Our study shows that, these initial funds will not result in immediate emission reduction. However, once climate finance to African countries crosses their estimate turning points, then the recipient countries can begin to sufficiently invest in cleaner energy sources and encourage innovations of environmental-friendly technologies to mitigate the effects of climate change. We

Table 6. Quantile regression estimates

Panel A: CO_2	Quantiles		
VARIABLES	25th	50th	75th
GDPP	0.0191	0.0353***	0.0289***
	(0.0197)	(0.0106)	(0.00961)
$GDPP^2$	−2.98e-06	−3.33e-06***	−2.39e-06**
	(2.66e-06)	(1.05e-06)	(9.44e-07)
CF	0.113**	0.296***	0.313***
	(0.0479)	(0.0915)	(0.0770)
CF^2	−6.95e-05***	−0.000160***	−0.000175***
	(2.30e-05)	(4.68e-05)	(4.81e-05)
ENC	0.0997**	0.149***	0.154***
	(0.0385)	(0.0170)	(0.0203)
GR	−159.9*	−141.2	−18.77
	(83.93)	(120.3)	(115.0)
REN	−0.328	1.907**	3.025***
	(0.688)	(0.737)	(0.524)
URB	−0.408	0.346	0.451
	(0.801)	(1.104)	(1.060)
FDI	2.02e-08***	2.30e-09	2.11e-09
	(6.70e-09)	(2.58e-09)	(2.07e-09)
Constant	35.49	−175.7	−274.1***
	(77.35)	(113.3)	(104.9)
GDPP TP	**$3204.69**	**$5300.30**	**$6234.31**
CF TP	**$812,000,000**	**$925,000,000**	**$894,00,000**
Observations	**171**	**171**	**171**
Panel B: CH4			
VARIABLES	25th	50th	75th
GDPP	0.00823***	0.00510*	0.00776
	(0.00196)	(0.00264)	(0.00994)
$GDPP^2$	−7.07e-07***	−4.26e-07*	−4.02e-07
	(2.28e-07)	(2.39e-07)	(6.62e-07)
CF	0.0342***	0.0114	0.00328
	(0.00888)	(0.0119)	(0.0251)
CF^2	−1.55e-05***	−3.23e-06	1.21e-07
	(5.67e-06)	(6.80e-06)	(1.15e-05)
ENC	0.00235	0.00728***	0.00134
	(0.00253)	(0.00274)	(0.00858)
GR	−25.94**	−34.57***	−10.01
	(12.92)	(7.113)	(46.48)
REN	0.172**	0.279***	1.119**
	(0.0776)	(0.104)	(0.556)
URB	−0.223***	−0.268*	0.873**
	(0.0706)	(0.157)	(0.366)
FDI	−2.40e-10	−3.71e-10	−2.50e-10

(*Continued*)

Panel A: CO_2	Quantiles		
	(6.21e-10)	(3.54e-10)	(1.86e-09)
Constant	−0.0284	12.43	−81.08
	(11.28)	(11.21)	(62.14)
GDPP TP	**$5820.37**	**$5985.92**	**$9651.74**
CF TP	**$1,103,000,000**	**$1,765,000,000**	**$1,355,000,000**
Observations	**171**	**171**	**171**
Panel C: N2O			
VARIABLES	25th	50th	75th
GDPPC	0.0126*	0.0312***	0.0333***
	(0.00662)	(0.00397)	(0.00440)
$GDPPC^2$	−8.79e-07	−2.41e-06***	−2.64e-06***
	(5.90e-07)	(3.71e-07)	(4.23e-07)
CF	0.0549***	0.0531***	0.0200
	(0.0163)	(0.0194)	(0.0174)
CF^2	−2.33e-05**	−2.32e-05*	−3.79e-06
	(1.05e-05)	(1.29e-05)	(1.01e-05)
ENC	−0.000374	0.000492	0.00305
	(0.00692)	(0.00533)	(0.00569)
GR	−73.54***	−95.88***	−93.12***
	(25.35)	(23.51)	(20.79)
REN	0.234	0.723***	0.708***
	(0.233)	(0.206)	(0.163)
URB	−0.592***	−1.164***	−1.429***
	(0.199)	(0.282)	(0.258)
FDI	3.18e-09	1.91e-09	2.17e-09***
	(2.74e-09)	(1.28e-09)	(6.58e-10)
Constant	25.55	22.72	43.89*
	(26.48)	(21.32)	(23.84)
GDPP TP	**$7167.24**	**$6473.03**	**$6306.82**
CF TP	**$1,178,000,000**	**$1,144,400,000**	**$2,638,000,000**
Observations	171	171	171

observe that the estimated turning points are well above the current annual averages received by most SSA countries and annual average investments of between $900 million and $2.6 billion would need to be pledged by donor countries to the SSA region for mitigation and adaptation solutions to climate change.

Lastly, the turning points estimated for both the traditional EKC and the climate finance-induced EKC, are much higher for CH4 and NO2 emissions compared to that of CO_2 emissions which probably reflects that most attention in addressing environment degradation is on carbon-based emissions at the expense of more dangerous air pollutants. This is of concern since African countries, through their reliance on farming activities, are more susceptible to the harmful effects nitrous oxide pollutants associated with fertilized soil and animal waste. Our findings suggest the need for climate funds to be geared towards finding innovative ways and testing emerging technologies to carry out agricultural

activities in a manner that minimizes CH4 and N2O emissions. Recently the World Bank pledged $14 million bond payment for projects related to the reduction of nitrous oxide and methane pollutants. Our findings indicate that these pledged amounts may not be sufficient enough to induce long-term and sustainable reductions on these pollutants.

Altogether, our study infers that both the levels of economic development as well as the pledges of climate finance from industrialized economies to African countries are currently not enough to reduce emissions and promote climate resilient economic activity. Our empirical findings also reveal that current levels of renewable energy as well as the current forms of foreign investment in African countries are not assisting in the fight against climate change and improved institutional quality is paramount towards reducing environmental degradation. Henceforth, policymakers should consider developing policies which will change the composition of FDI towards environmentally friendly projects and further ensure that the resourced climate funds are not misdirected due to corruption and poor regulatory quality. As more climate finance data becomes available, one possible avenue for future research, would be to extend our current analysis to the individual recipient countries in order to identify unique per capita income and climate finance "turning points" within the EKC for each nation. Moreover, future studies could focus on the role which climate finance has played in reducing deforestation in African countries.

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