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Foreign direct investment and renewable energy in climate change mitigation: Does governance matter?

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ABSTRACT

Climate change mitigation is a topical issue with growing debate in the context of the renewable energy transition, global partnership, governance, and economic growth. The complexness of climate change makes it difficult to predict relationships and formulate policies across varied countries. Motivated by the core mandate of the Kyoto Protocol, we examined the individual, combined and interactive impact of growth in income, renewable energy, foreign direct investment, and governance on greenhouse gas emissions. We decomposed the relationships to account for the theories of scale effect, composition effect and technique effect. The study utilized a dynamic heterogeneous estimation technique with a panel data from 1990 to 2017 in 47 Sub-Saharan African countries. Our adopted empirical framework made it possible to account for heterogeneity, a situation that may be prevalent in countries with varied economic and environmental policies. The empirical results revealed that increasing the share of renewable energy by 1% declines greenhouse gas emissions by as much as 35.32% (95% Confidence interval) while a 1% increase in the coupling effect of income level, governance, and renewable energy consumption intensifies climate change by 0.79%. The interactive effects of scale, composition, and technique indicators were found to worsen climate change. The decoupling effect revealed that while foreign direct investment, income level, and governance exacerbate climate change, renewable energy consumption lessens climate change and its impact. From a policy perspective, the magnitude of the technique effect of renewable energy consumption depends on, *inter alia*, its share in the energy portfolio, technological innovation, and country-specific policy instruments. The study demonstrated that decoupling renewable energy from economic growth propels the transition from fossil fuels, leading to energy efficiency— explaining the decline in GHG emissions.

1. Introduction

Rising energy consumption in the Sub-Sahara Africa (SSA) region has resulted in the emission of harmful greenhouse gases (GHGs) to the atmosphere — increasing climate change-related challenges. It is therefore not surprising that there is an intense debate on mitigating the negative effects of climate change driven mostly by conventional sources of energy (IRENA, 2018; Africa Progress Panel, 2018) Climate change and energy consumption are two critical issues that affect the performance of economic growth, particularly in SSA. Carbon dioxide (CO_2) is the most abundant of all the GHGs — as it accounts for over 70% of emissions (Sanglimsuwan, 2011; IPCC, 2007; Lau et al., 2014). Environmental pollution in the past was mostly associated with CO_2 emissions from developed countries but in recent times, developing countries have received much attention due to rapid economic growth and industrialization (Elum and Momodu, 2017). Though SSA pollutes less but more susceptible to the adverse effects of global warming including food shortage resulting in hunger, flooding, and salt intrusion (Samaras and Vouitsis, 2013). The negative effects of global warming have prompted a new focus on clean and renewable energy sources to reduce CO_2 emissions while mitigating climate change (Wang et al., 2018; Urban, 2018). The Sustainable Development Goal (SDG) 7 gives credence to ensuring the accessibility of clean, affordable, reliable modern energy.

The IEA (2017) describes energy as the 'golden thread' connecting growth, equity, and sustainability. The report further reveals that access to energy is crucial to achieving the SDGs. More

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importantly, the ability of Africa to leapfrog into a new era of growth trajectory will require a transition into low carbon efficient modern energy that provides energy for all. While several studies have examined the effect of energy consumption— particularly renewable energy on CO_2 emissions, there is a dearth of the empirical literature on the nexus between renewable energy and climate change to provide evidence-based policy recommendation. The objective of the study examines the effect of heterogeneous income level, foreign direct investment (FDI) and renewable energy on GHG emissions while accounting for the quality of governance. This is relevant in the sense that the SSA region has the highest energy poverty in the world with over half a billion population without access to electricity (World Health Organization, 2015), hence, the transition to renewables as a source of energy supply cannot be ignored. This is even more critical because the region is abundant in many low carbon energy sources including hydro, solar, biofuel, and wind systems (IEA, 2017). Thus, the drive for renewables does not just make economic sense, but also pragmatic for SSA countries to leverage on its abundant resources for the transformation and improvement of livelihoods. What these studies show is that not only could renewables improve access to electricity, but also promote growth, employment and consequently reduce poverty and income inequality (Solt, 2016; Africa Progress Panel, 2018). It is argued that renewable energy could provide many social benefits in terms of quality of health, education and gender equality (Wang et al., 2018).

FDI is suggested to play a key role in promoting economic development through its beneficial effects on both environmental sustainability and economic growth (Abdouli and Hammami, 2017; Adams, 2009; Adams et al., 2016). Advocates have thus, recommended developing countries to institute policies that attract foreign direct investment inflow. Foreign direct investment inflows have since reached \$71 billion in 2014 after doubling in 2006 (\$36 billion) from US\$ 18 billion in 2004. However, due primarily to weak oil and commodity prices, FDI inflows have declined to \$61 billion in 2015, \$59 billion in 2016 and \$42 billion in 2017 (WIR, 2008; 2017, 2018). In contrast, three of the top four FDI destinations in SSA experienced an increase (namely Ghana, Ethiopia, and Nigeria) except for one (Angola), which experienced a decline in inflows. The lingering question that requires an answer is how FDI inflows impact environmental sustainability. The validity of either the pollution haven hypothesis (PHH) or pollution halo hypothesis (PH) is tested in this study. It is worthy of mention that these four countries are among the top renewable energy producers (IRENA, 2018). This also affords the opportunity to investigate the individual effects of renewable energy and FDI and their interaction or combined effect on GHG emissions. The argument here is that if both the individual and interactive effects are significant then the many studies that have examined the independent effects of renewable energy (York and McGee, 2017) and FDI (Kostakis et al., 2017) on climate change could be suffering from omitted variable bias.

There is a vast literature that suggests that government policy or governance environment is critical in explaining climate change. However, there is not much empirical evidence especially in the context of SSA and even for the few that exists the results are inconclusive. This study adds to the literature by examining the role of political institutions quality in climate change mitigation. This argument is consistent with Walter and Ugelow (1979, p.102) that the translation of existing or expected environmental problems into corrective or preventive environmental policy depend on social and political factors at both national and regional levels. More important, the authors note that identical objectively perceived environmental damage may be accorded quite different social weights in different countries. Many studies have thus far not examined the issues comprehensively as done by this study. For example, Kostakis et al. (2017) examined the effect of FDI and renewable energy respectively on environmental degradation, while Mert and Bölük (2016) investigated FDI and renewable energy on environmental degradation without controlling for the economic and political institutions. In a recent study of African countries, Bopkin et al. (2017) investigated the effect of FDI and institutions without accounting for the political and renewable energy variables. In a related study, Bopkin (2017) examined the effect of FDI and governance on environmental degradation but the governance variable was proxied with democracy. It is the argument of this paper that the inconsistency of many of the results reported could be attributed to the omitted variable bias and more particularly the context being considered, which necessitates this study.

We examine the nexus under the theories of scale, composition and technique effects by controlling from heterogeneity across SSA countries. The scale effect posits that the path of economic development is characterized by natural resource depletion and waste generation. In the composition effect, structural adjustments in the trajectory of economic development underpin the changes in environmental pollution. In the technique effect, the emergence of technology, innovation, research and development at higher economic development lead to a cleaner environment (Grossman and Krueger, 1991; Panayotou, 1997). Thus, a critical assessment of these effects is useful for policy formulation.

The remainder of the study is structured as follows: Section 2 covers a brief literature review on the scope of the study; Section 3 outlines the Materials & Method used for the model estimation; Section 4 presents the Results & Discussion of the estimated model parameters whereas Section 5 summarizes the key findings of the study and its policy implication.

2. Literature review

PHH and PH are the two main theoretical frameworks used to explain the FDI – environmental degradation relationship. The PH suggests that FDI is expected to have a positive effect on both economic growth and the environment through the increase in total investment and production efficiency (Adams, 2008). The influx of FDI to poor countries helps in the transfer of technology and management practices that cause lower carbon emissions in developing countries (Zarsky, 1999). Lee (2013) explained that the externalities associated with productivity gains promote the use of more efficient energy sources and subsequently improving environmental quality. The influx of FDI into developing countries could help promote both industrial competitiveness and environmental quality (Stavropoulos et al., 2018).

The PHH, on the contrary, argues that new investment projects in the advanced countries that are restricted for environmental reasons look for opportunities in the developing countries with laxed environmental policies (Walter and Ugelow, 1979). This shifts the international production allocation from developed countries (high-pollution levels) to developing countries (low-pollution levels) — having the dual effect of promoting industrialization in the poor countries and using more efficient global available environmental resources. The PHH is also explained by the H–O theory in which environmental factors are factors of production, so production cost increases due to the stringency of environmental regulation (Stavropoulos et al., 2018). Accordingly, countries with laxed environmental regulations will have a comparative advantage in attracting more FDI and with the possibility of declining environmental sustainability (Siebert, 1977).

In support of the theoretical assertions, many empirical studies have been conducted to provide evidence or otherwise. For example, a study confirmed that foreign-owned enterprises in China outpaced indigenous enterprises in terms of reducing sectoral emission. It was reported that the influx of FDI helped Chinese firms to experience fast upgrades of emission intensity-related technologies (Jiang et al., 2015). They concluded that FDI could serve as a very effective channel for technology transfer to developing countries. Similarly, FDI was found to positively impact environmental quality in Vietnam (Tang and Tan, 2015). The results showed that the significance of the relationship between CO_2 emission, energy consumption, urbanization, and FDI is based on the growth of income. While the results showed that primary energy and fossil fuels promote environmental pollution, energy consumption affected emissions compared to FDI in middle-income countries. Zhang and Zhou (2016) found support for the pollution halo hypothesis as foreign firms export greener technologies to host countries and conduct business in an environmentally friendly manner. The findings of Salahuddin et al. (2017) show that energy consumption, FDI and economic growth do cause a substantial increase in CO_2 emissions. In a similar study in six SSA countries, Kivyiro and Arminen (2014) reported energy consumption and FDI-driven environmental degradation. A related study of the effect of international trade and FDI on carbon emissions in China, Ren et al. (2014) using an output analysis based on two-step GMM estimation technique reported trade and FDI intensify CO_2 emissions in China. Koçak and Şarkgüneşi (2018) found support for both the EKC and the PHH in Turkey for the period 1974–2013. Likewise, Lau et al. (2014) confirmed that FDI and trade are key ingredients of environmental pollution in Malaysia over the period 1970–2008. They recommended that more attention be given to the attraction of technology-oriented FDI that are environmentally friendly.

The findings of Riti et al. (2017) showed that renewable energy, financial development, and population growth have a positive effect on environmental quality, while conventional sources of energy negate environmental sustainability. Hu et al. (2018), however, showed that increasing the size of renewable energy consumption had the contrary effect. Sarkodie and Adams (2018) demonstrated that fossil fuels and renewable energy have opposite effects on the environment while the institutional variable was pro-environment in South Africa. Liu et al. (2017) indicated that both renewable energy and agricultural value-added decrease CO_2 emissions while non-renewable energy is positively correlated with emissions.

Studies that investigate the coupling effect of FDI and renewable energy on environmental pollution are limited. While Bakhsh et al. (2017) and Ozturk (2017) confirmed the pollution haven hypothesis (i.e. FDI causes environmental pollution and renewable waste), both Paramati et al. (2017) and Mert and Bölük (2016) validated the pollution halo hypothesis (i.e. FDI and renewable energy are pro-environment) in G20 countries and 21 Kyoto Annex countries, respectively.

Our study is in line with other studies that consider FDI and emission in the same regression but is novel in the sense that we examine the interactive effect of the duo while accounting for governance quality, hence, reducing omitted variable bias. It is noteworthy that few other studies [Bopkin et al. (2017), Lau et al. (2018)] have examined the role of institutional factors or governance infrastructure in mitigating the negative effects of global warming and consequently climate change. These studies fail to account for heterogeneous distribution, a situation that is evident and challenging in socio-economic series based on panel data settings. Existing literature suggests that the relationship between FDI, renewable energy, and environmental degradation is an empirical matter and cannot be determined *a priori.* We provide a comprehensive empirical analysis of the scope of the study in line with the SDGs. The methodology for achieving this objective is discussed next.

3. Materials and methods

In this section, we elaborate on the data processing technique, construction of variables and model estimation techniques utilized prior to the empirically-based analysis.

3.1. Construction of variables

Data availability underpin the adoption of variables from 1990 to 2017 in 47 Sub-Saharan African countries (See Appendix A). Table 1 presents a description of the data series. Total greenhouse gas emissions (GHG), Foreign direct investment net inflows (FDI), GDP per capita (GDPPC), and Renewable Energy Consumption (RNEW) were retrieved from World Bank (2018), while Political institutional quality (GOVERN) —used as a proxy for Governance was retrieved from Quality of Government Institute (UoG, 2017). Fig. 1 shows *a priori* interaction between GHG emissions, GDP per capita, FDI, renewable energy, and governance. The dependent variable (GHG) is a measure of the total anthropogenic carbon dioxide emissions (excluding sources from agricultural waste and savannah burning), Methane, Nitrous oxide, and Fluorinated gases such as Sulphur hexafluoride, Perfluorocarbons, and Hydrofluorocarbons. Though other variables including GHG contribute to climate change, however, GHG is the key driver of climate change (Phillips et al., 2020; Storelvmo et al., 2016). The adoption of GHG as a proxy for climate change is a useful indicator for assessing the direct impact of emissions. FDI measures the direct investment flows from cross-border re-investment of earnings, equity capital and other capital (World Bank, 2018). According to the World Bank, FDI is a useful indicator for assessing technological transfer, tracking the implementation of the Sustainable Development Goals, private sector growth, and investment climate, especially in developing countries. Thus, FDI has both composition and technique effects on GHG emissions. GDPPC measures the total gross value of indigenous economic producers plus taxes on products excluding subsidies, degradation, and depletion of available natural resources. GDPPC is a useful indicator for assessing the changes in the local production of goods and services without accounting for the environmental and social cost associated with production and consumption (DiSano, 2002). Hereafter, GDPPC has a *scale effect* on climate change mitigation. RNEW accounts for the share of renewable energy in the total final energy utilization. The technique effect of RNEW on GHG emissions stems from its role in the reduction of environmental degradation, energy security and diversification of the energy mix — hence, underpins the attainment of the SDGs (Owusu and Asumadu, 2016). GOVERN measures corruption perception and control, democracy, accountability, freedom of the press, political rights, bureaucracy quality, conflicts, political terror and military aided politics (Kunčič, 2014). For the technique effect of governance to operate, willingness to pay for cleaner environment among citizens increases with increasing demand for a sustainable environment, informal pressures make government responsive — raising environmental pollution cost as income level increases. Hence, political institutional quality plays a

Table 1
Description of data series.

Variable	Abbreviation	Unit
Total greenhouse gas emissions	GHG	kt of CO_2 equivalent
Foreign direct investment net inflows	FDI	current US$
GDP per capita	GDPPC	current US$
Political institutional quality	GOVERN	relative factor scores
Renewable Energy Consumption	RNEW	%

Notes: Data series are extracted from World Bank (2018).

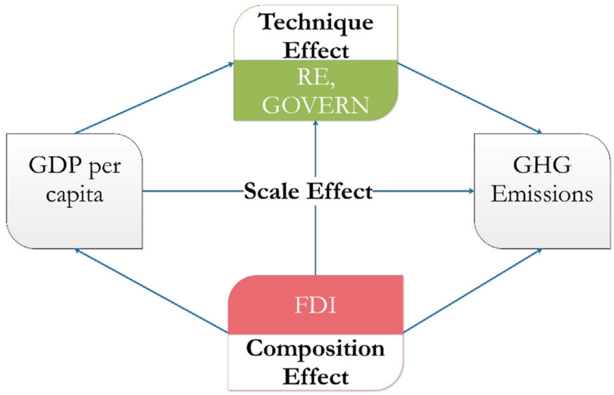

Fig. 1. A priori interaction between GHG emissions, GDP per capita, FDI, renewable energy, and governance. **Source:** Authors' construction.

critical role in environmental policies that mitigate climate change and impacts.

In other to account for uncertainties in subsequent statistical inferences due to missing values in the dataset, the study adopted the model-based simple tree and average imputation algorithms available in Python-based Orange as preprocessing techniques (Murray, 2018). Appendix B presents the descriptive statistical analysis to examine the characteristics of both raw and imputed data series. Previous studies (Ergun et al., 2019) either ignore negative series or use absolute values in a subsequent model estimation, which are erroneous since the series loses its structure. To control for negative data series without losing its structure, the study applied the normalization technique to scale all the variables within the same range without losing its trend. The normalization equation follows:

$$Z'_{i,t} = \frac{100(Z_{i,t} - Z_{i,t_{min}})}{Z_{i,t_{max}} - Z_{i,t_{min}}} \quad (3.1.1)$$

Where Z' is the normalized data, Z is the values of the input raw data series, i represents the country at time t.

3.2. Model estimation

This sub-section outlines the empirical analysis of the model estimation techniques employed in the study. Contrary to the limitations of time series and cross-sectional data, the study employed panel data estimation techniques which allow the investigation of the individual differences and dynamics of the selected countries — an advantage over the two. The study proceeded to test the unit root process of the data series. From a policy perspective, testing panel unit root is essential to know if the fluctuations in the data series are permanent or transitory. After testing for panel unit root, the study examined the cointegration between the dependent variable and regressors using Kao (1999), Pedroni (2004) and Westerlund (2005) panel cointegration tests. Nonstationary data series have a characteristic of wandering, hence, cointegration applies only to nonstationary data series to ascertain the tendency of a stable long-run relationship. To make an informed decision with regards to the selection of a model estimation method, we examined the homogeneity of the process coefficient using slope equality test via quantile-based panel regression. According to Pesaran and Smith (1995), homogeneity-based model estimators produce inconsistent results in dynamic heterogeneous panel parameter models, hence, proposed a panel estimator that controls for heterogeneity across a panel of countries —a challenge evident in this study. Studies confirm that inconsistent model estimates are due to serial correlation-induced error term — when heterogeneity of panel parameters is ignored (Eberhardt and Teal, 2017; Pesaran and Smith, 1995). Based on the results of the process coefficient using slope equality test via panel quantile regression, heterogeneity of parameters was observed across countries, justifying the adoption of heterogeneous mean group panel estimator by Pesaran and Smith (1995) for subsequent econometric analysis. The linear relationships of the proposed models follow:

$$lnGHG_{i,t} = f(lnX_{i,t}) \quad (3.2.1)$$

Where $lnGHG$ represents the natural log of the dependent variable while lnX denotes the independent variables ranging from individual to interactive data series.

Following Pesaran and Smith (1995), the specification of equation (3.2.1) can be expressed as:

$$lnGHG_{i,t} = \alpha_i + \beta_i{*}lnX_{i,\ t} + v_{i,\ t} \ for\ i = 1,\ \ldots,\ 47\ and\ t = 1,\ \ldots,\ 28\ years \quad (3.2.2)$$

Where α_i represents the country-specific fixed effects, β_i denotes the slope coefficient of individual countries (i) on the regressors and v represents the unobservable error term in time$t$ (years). The mean group estimator employed in the study first estimates the group-specific regression and implements the unweighted average of the estimated coefficients across countries. Equation (3.2.2) is estimated for individual countries with an intercept to control for fixed effects.

The resulting equations for our thirteen models can be expressed as follows:

$$\text{Model 1}: lnGHG_{i,t} = \alpha_i + \beta_{1,\ i}lnFDI_{i,\ t} + \beta_{2,\ i}lnGDPPC_{i,\ t} + \beta_{3,\ i}lnRNEW_{i,\ t} + \beta_{4,\ i}lnGOVERN_{i,\ t} + v_{i,\ t} \quad (3.2.3)$$

Here, we control for omitted variable bias by accounting for the effect of foreign direct investment inflows, growth of income, renewable energy consumption and governance on climate change.

$$\text{Model 2}: lnGHG_{i,t} = \alpha_i + \beta_{1,\ i}lnFDI_{i,\ t} + v_{i,\ t} \quad (3.2.4)$$

In this model, we examined the individual effect of foreign direct investment inflows on climate change without accounting for other variables. We expect either a positive or negative coefficient, validating either pollution haven or pollution halo hypothesis.

$$\text{Model 3}: lnGHG_{i,t} = \alpha_i + \beta_{1,\ i}lnGDPPC_{i,\ t} + v_{i,\ t} \quad (3.2.5)$$

While ignoring other variables, the impact of income levels on climate change across Sub-Saharan African countries was estimated. A positive coefficient on GDPPC is the expected *a priori* to confirm the scale effect hypothesis for agrarian-based economies in developing countries.

$$Model\ 4:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i}lnGOVERN_{i,\ t} + v_{i,\ t} \quad (3.2.6)$$

We expect either a positive or negative impact of heterogeneous political institutional quality on climate change due to the diverse political environment such as, *inter alia*, autocratic, and democratic forms of governance in Sub-Saharan Africa.

$$Model\ 5:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i}lnRNEW_{i,\ t} + v_{i,\ t} \quad (3.2.7)$$

Renewable energy consumption plays a critical role in Sub-Saharan Africa's energy mix, as such, if emissions are less in the sub-region compared to other jurisdictions, then, — a negative coefficient is expected on the effect of renewable energy on climate change.

$$Model\ 6:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i} ln(GDPPC)_{i,\ t} + \beta_{2,\ i} ln(GOVERN)_{i,\ t} + \beta_{3,\ i} ln(GDPPC{*}GOVERN)_{i,\ t} + \nu_{i,\ t} \quad (3.2.8)$$

In Fig. 1, income level is categorized under scale effect while governance is classified under technique effect. Thus, we examined the interactive effect of income level and governance on climate change. We expect either a positive or negative coefficient on the interactive effect, depending on which variable outweighs the other.

$$Model\ 7:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i} lnRNEW_{i,\ t} + \beta_{2,\ i} lnGDPPC_{i,\ t} + \beta_{3,\ i} ln(GDPPC{*}RNEW)_{i,\ t} + \nu_{i,\ t} \quad (3.2.9)$$

This model examined the interaction between the scale effect of income level and the technique effect of renewable energy consumption. We expect the domineering effect of income level to suppress renewable energy, hence, a positive impact of the interactive effect on climate change is expected.

$$Model\ 8:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i} lnFDI_{i,\ t} + \beta_{2,\ i} lnGDPPC_{i,\ t} + \beta_{3,\ i} ln(FDI{*}GDPPC)_{i,\ t} + \nu_{i,\ t} \quad (3.2.10)$$

The interaction between the composition effect of foreign direct investment inflows and the scale effect of income level on climate change was estimated. The composition effect of foreign direct investment inflows increases economic development, as such, we expect a positive interactive effect on climate change.

$$Model\ 9:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i} lnFDI_{i,\ t} + \beta_{2,\ i} lnGDPPC_{i,\ t} + \beta_{3,\ i} lnGOVERN_{i,\ t} + \beta_{4,\ i} ln(FDI{*}GDPPC{*}GOVERN)_{i,\ t} + \nu_{i,\ t} \quad (3.2.11)$$

This model regressed the climate change component on the interaction between foreign direct investment inflows, growth in income and governance. A positive interactive effect of the trio is expected on climate change.

$$Model\ 10:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i} lnFDI_{i,\ t} + \beta_{2,\ i} lnGDPPC_{i,\ t} + \beta_{3,\ i} lnRNEW_{i,\ t} + \beta_{4,\ i} ln(FDI{*}GDPPC{*}RNEW)_{i,\ t} + \nu_{i,\ t} \quad (3.2.12)$$

The triad effect of FDI, income level and renewable energy on climate change was examined. Due to the driving force of the two economic variable that outweighs the effect of renewable energy, a positive coefficient is expected on the interactive indicator.

$$Model\ 11:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i} lnGDPPC_{i,\ t} + \beta_{2,\ i} lnGOVERN_{i,\ t} + \beta_{3,\ i} lnRNEW_{i,\ t} + \beta_{4,\ i} ln(GDPPC{*}GOVERN{*}RNEW)_{i,\ t} + \nu_{i,\ t} \quad (3.2.13)$$

This model investigated the impact of a triad indicator with an economic, socio-political and environmental component on climate change. Due to the governance structure in Africa, agrarian-based economy and biomass-dominated renewable energy consumption, a positive effect of the interaction on climate change is expected.

$$Model\ 12:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i} lnFDI_{i,\ t} + \beta_{2,\ i} lnGDPPC_{i,\ t} + \beta_{3,\ i} lnRNEW_{i,\ t} + \beta_{4,\ i} lnGOVERN_{i,\ t} + \beta_{5,\ i} ln(RNEW{*}GOVERN)_{i,\ t} + \nu_{i,\ t} \quad (3.2.14)$$

$$Model\ 13:\ lnGHG_{i,t} = \alpha_i + \beta_{1,\ i} lnFDI_{i,\ t} + \beta_{2,\ i} lnRNEW_{i,\ t} + \beta_{3,\ i} ln(FDI{*}RNEW)_{i,\ t} + \nu_{i,\ t} \quad (3.2.15)$$

4. Results

We examined the characteristics of the data series using descriptive statistics presented in Appendix B. Choropleth maps presented in Figs. 2–6 were used to statistically observe the mean distribution of variables across countries. Fig. 2 reveals that the minimum average total greenhouse gas emissions of 5716 kt of CO_2 equivalent occur in Sao Tome and Principe while Congo (Kinshasa) has the maximum concentration of greenhouse gas emissions (853,047 kt of CO_2 equivalent). The high levels of GHG emissions in DR Congo can be attributed to the rising levels of land-use change and forestry. According to USAID (2018), ~80% of GHG emissions in Congo (Kinshasa) is caused by land-use change and forestry while ~20% emissions are from agriculture, energy, waste, and industrial production. Fig. 3 shows that Botswana has the maximum average political institutional quality (good governance) across Sub-Saharan Africa while Sudan fares poorly in terms of good governance. Botswana's good governance can be attributed to the upholding of rule of law (enactment, administration, and enforcement), sound and stable democracy, the existence of quality and competent Executive, Legislature and Judiciary institutions. Fig. 4 presents an interesting average distribution of income levels across countries. Equatorial Guinea has the maximum average income level of ~US$ 8195 compared to below ~ US$ 2000 distributed across 35 countries. The high-income level of Equatorial Guinea can be attributed to their rich oil resources exploited mainly for export; however, the United Nations (UN, 2016) opine that their vast resources and oil wealth are not used to reduce vulnerability and human assets development. The average share of renewable energy consumption across countries is presented in Fig. 5. South Africa remains the country with the minimum renewable energy penetration (~21%) in Sub-Saharan Africa while 39 countries have between ~50 and 95% share of renewable energy in the energy mix. South Africa's energy mix is mainly dominated by coal energy consumption, while natural gas, oil and nuclear plays auxiliary roles (Bekun et al., 2019; Sarkodie and Adams, 2018). The average distribution of FDI net inflows across countries is depicted in Fig. 6. Accordingly, Nigeria receives the maximum average foreign direct investment of about US$ 3,418,164,292 — followed closely by South Africa, while the remaining 45 countries receive investment below

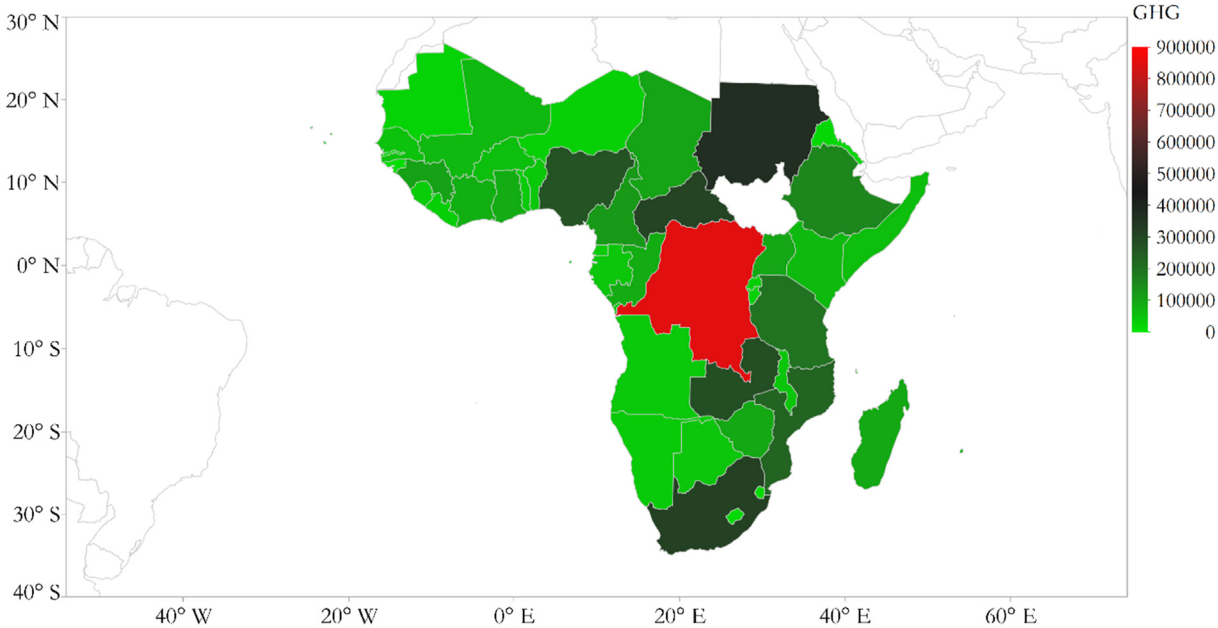

Fig. 2. Average distribution of total greenhouse gas emissions across countries (kt of CO_2 equivalent). **Source:** Authors' construction.

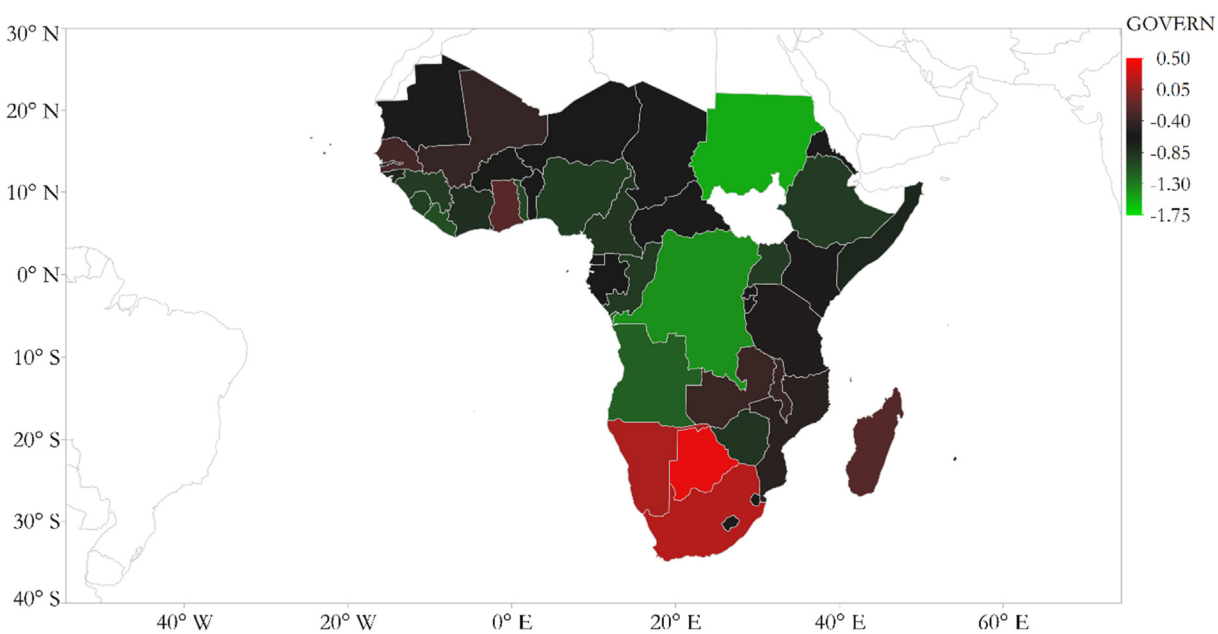

Fig. 3. Average distribution of political institutional quality across countries (factor scores). **Source:** Authors' construction.

US$ 1,300,000,000. Apart from Nigeria's endowment of natural resources, the higher levels of FDI can be attributed to its role as the largest consumer market in Africa — due to its population and purchasing power.

After examining the characteristics of the data series, the study proceeded to test for the panel unit roots presented in Appendix C. Panel unit root testing is a standard procedure in econometrics to prevent spurious regression. From a policy perspective, we utilized the tests of panel unit root to ascertain whether fluctuations in GHG emissions, FDI, growth in income, governance, and renewable energy consumption were permanent or transitory. Both Breitung and Hadri panel unit root tests confirm that all the data series are integrated of order one [I(1)] (Appendix C). Since both the dependent series (GHG emissions) and the regressors are I(1) variables, the concept of panel cointegration becomes meaningful in this study. Panel cointegration tests specifically — Kao, Pedroni, and Westerlund were utilized based on the "*null hypothesis of no cointegration*". The empirical evidence in Table 2 confirms a level relationship between GHG emissions and the regressors. After confirming the notion of cointegration, the study proceeded to test for slope heterogeneity using panel quantile estimation technique proposed by Koenker and Bassett (1982). The slope equality-based results in Table 2 reveal that the Chi-squared (χ^2) statistic is statistically significant (1% level) at conventional test levels in 9 out of 13 estimated models. Hence, confirming evidence of heterogeneous coefficients across conditional quantiles in nine models.

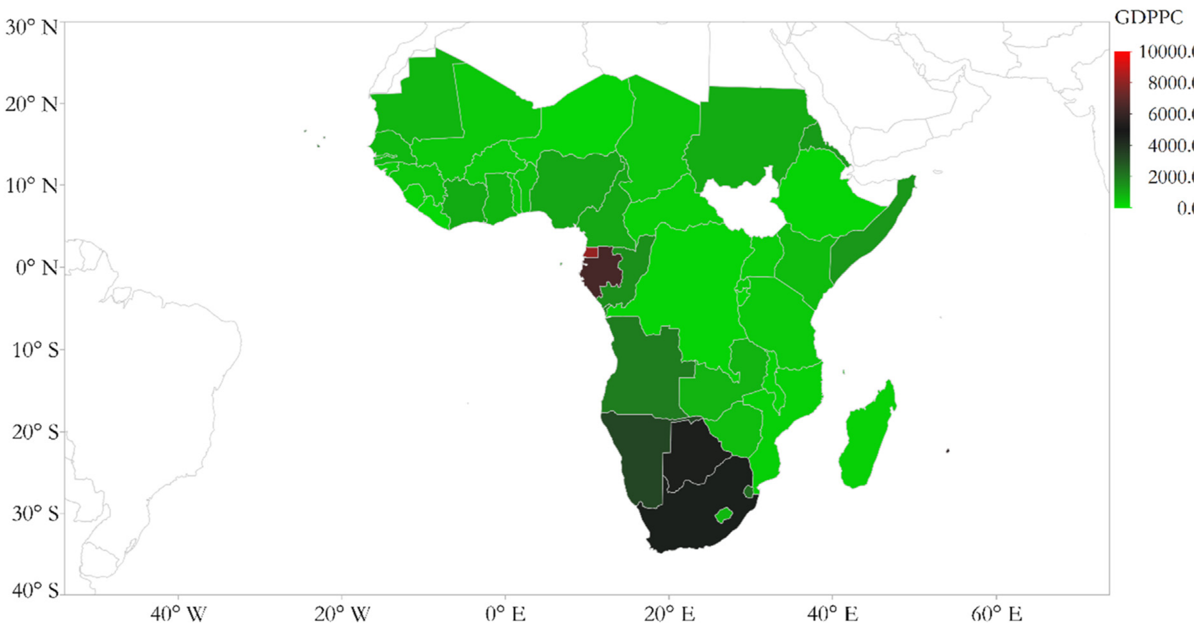

Fig. 4. Average distribution of GDP per capita across countries (current US$). **Source:** Authors' construction.

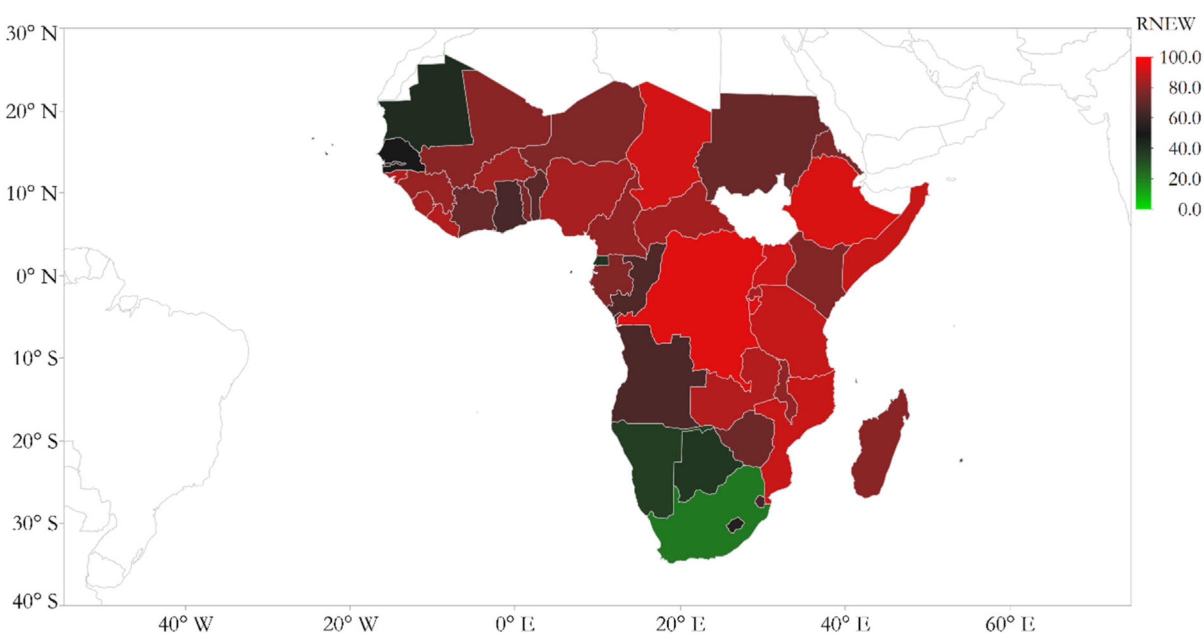

Fig. 5. Average renewable energy consumption distributed across countries (%). **Source:** Authors' construction.

Using Pesaran's Mean Group estimator, we controlled for heterogeneity of slope coefficients across countries. Table 2 presents the results of the estimated models with their corresponding diagnostic tests based on 1316 observations and 47 cross-sectional units. All the estimated models show Wald test (Wald χ^2) values that are statistically significant at 5% level (*p-value < 0.05*) and root mean square error (RMSE) ranging from 0.83 to 1.12.

In model 1 (**M 1**), we controlled for omitted variable bias by regressing GHG emissions on income level, FDI and renewable energy consumption while accounting for governance. Excluding income level, no statistical significance is observed from the remaining regressors. A 1% increase in the ceteris paribus effect of income level is found to increase GHG emissions by 0.60% (99% *Confidence Interval [C.I.]*).

Model 2–5 (**M 2 - M 5**) examined the composition effect of FDI, scale effect of income level and the technique effects of governance and renewable energy consumption on GHG emissions —evidenced in Table 2 (column 3–6). The coefficient on FDI is positive and statistically significant at 5% level. Empirically, a percentage increase in FDI inflows exacerbates GHG emissions by 35.90% — confirming the pollution haven hypothesis in Sub-Saharan Africa. We confirm a significant (99% C.I.) positive coefficient on income level — GHG emission nexus. A 1% increase in income level intensifies GHG emissions by 0.61%. A weak significant (90% C.I.) positive coefficient on governance — GHG emission relationship is observed. The technique effect of renewable energy consumption on GHG emissions is validated— as

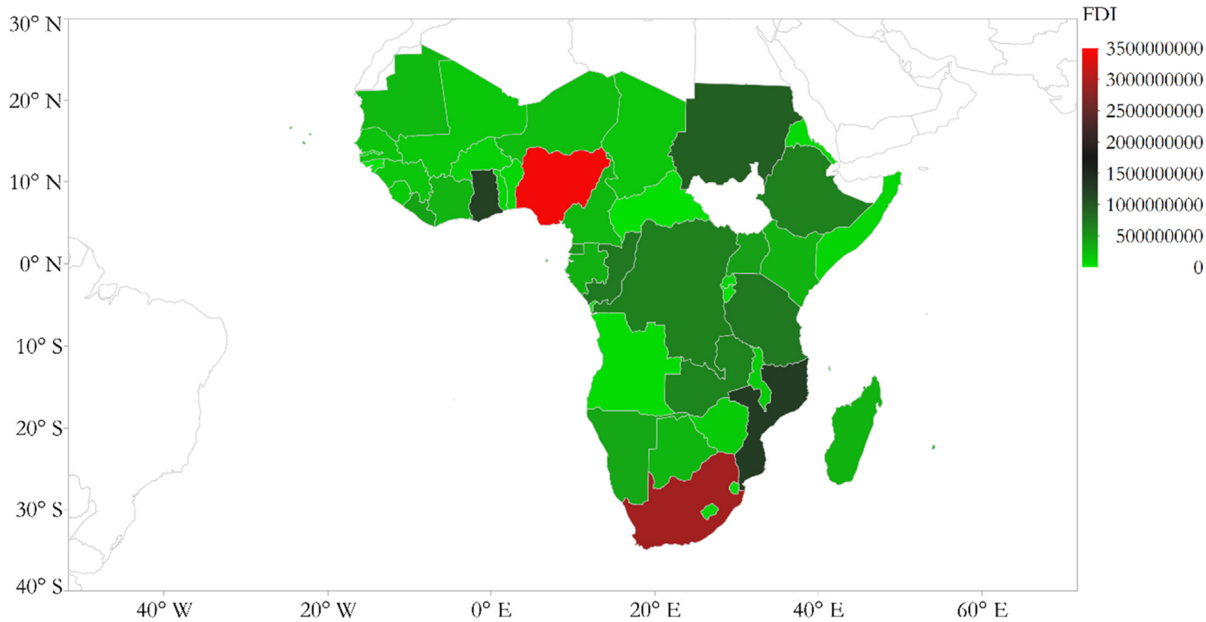

Fig. 6. Average distribution of foreign direct investment net inflows across countries (current US$). **Source:** Authors' construction.

Table 2
Dynamic heterogeneous parameter models.

GHG	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13
FDI	5.61 [7.60]	35.90** [18.30]	–	–	–	–	–	–	5.81 [6.11]	3.30 [7.85]	–	5.61 [7.60]	–
GDPPC	0.60* [0.15]	–	0.61* [0.14]	–	–	0.19 [0.15]	1.31 [0.87]	–	–	0.85 [0.14]	–	0.60* [0.16]	–
GOVERN	0.28 [0.17]	–	–	0.32*** [0.17]	–	–	–	–	–	–	–	–	–
RNEW	−0.17 [0.91]	–	–	–	−1.64** [0.83]	–	–	–	–	–	−1.39*** [0.80]	−0.46 [0.88]	−35.32** [16.89]
RNEW*GOVERN	–	–	–	–	–	–	–	–	–	–	–	0.29 [0.31]	–
GDPPC*GOVERN	–	–	–	–	–	0.43* [0.14]	–	–	–	–	–	–	–
FDI*RNEW	–	–	–	–	–	–	–	–	–	–	–	–	34.33** [17.01]
GDPPC*RNEW	–	–	–	–	–	–	−0.67 [0.87]	–	–	–	–	–	–
FDI*GDPPC	–	–	–	–	–	–	–	7.72 [7.74]	–	–	–	–	–
FDI*GDPPC*GOVERN	–	–	–	–	–	–	–	–	3.39 [4.37]	–	–	–	–
FDI*GDPPC*RNEW	–	–	–	–	–	–	–	–	–	−0.26 [0.89]	–	–	–
GDPPC*GOVERN*RNEW	–	–	–	–	–	–	–	–	–	–	0.79*** [0.41]	–	–
_CONS	−21.30 [28.72]	−134.78** [68.84]	−0.39 [-0.39]	−0.90 [0.67]	8.05** [3.64]	−0.36 [0.50]	0.24 [0.54]	0.98 [1.51]	−21.62 [22.94]	−12.24 [29.36]	5.86*** [3.52]	−20.14 [28.68]	27.89** [11.31]
Cointegration	Yes[b, c, d]	Yes[b, c, d]	Yes[b, c, d]	Yes[c]	Yes[b, c, d]	Yes [c]	Yes[b, c, d]	Yes[c, d]	Yes[b, c, d]	Yes[b, c, d]	Yes[b, c, d]	Yes[b, c, d]	Yes[b, c, d]
Diagnostics													
RMSE[a]	0.83	1.06	1.03	1.12	1.06	1.01	0.92	0.96	0.94	0.85	0.90	0.83	0.95
Wald χ^2	23.66	3.85	20.05	3.78	3.88	22.04	17.88	14.30	16.00	18.01	26.16	22.27	6.27
Prob > χ^2	0.00*	0.05**	0.00*	0.05**	0.05**	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.00*	0.05**
Slope Equality: χ^2 *p-value*	0.00*	0.00*	0.13	0.08***	0.03**	0.28	0.21	0.07***	0.06***	0.11	0.01**	0.00*	0.00*

Notes: ***M1-M13*** represents Model 1 to Model 13; while some variables were dropped because of collinearity, insignificant models were not reported. [a]Root Mean Squared Error (sigma); *, **, *** denote the rejection of the null hypothesis at 1, 5, and 10% significance level; ***Yes*** — denotes the rejection of the null hypothesis of no cointegration; [b]Westerlund, [c]Kao, [d]Pedroni cointegration tests.

the output shows a significant (95% C.I.) negative coefficient on RNEW. Meaning that increasing the share of renewable energy by 1% negates climate change by 1.64%.

Model 6–11 (**M 6 - M 11**) assessed the interactive effect of the regressors on climate change. In model 6, we examined the technique effect of governance and income level on climate change mitigation. The coefficient on GHG ~ *f*[GDPPC*GOVERN] is positive and statistically significant ($p < 0.01$) —showing that a percentage increase in the coupling effect of income level and governance negates environmental sustainability by 0.43%. Model 7 assessed the impact of the interaction between income level and renewable energy consumption on climate change but produced insignificant results —though showing a negative effect. Model 8 investigated the composition effect of FDI and income level on climate change. The results of FDI*GDPPC revealed an insignificant positive coefficient on GHG.

In model 9–11, we analyzed a trio-interaction effect between FDI, income level and governance; FDI, income level and renewable energy consumption, and income level, governance and renewable energy consumption on climate change. The empirical results reveal a statistically significant ($p < 0.10$) positive triad effect of GDPPC*GOVERN*RNEW on climate change while the coefficient on FDI*GDPPC*GOVERN is insignificant. Thus, a 1% increase in the triumvirate indicator GDPPC*GOVERN*RNEW) intensify climate change by 0.79%. In contrast, a percentage increase in renewable energy consumption declines climate change by 1.39%.

In Models 12–13 (**M 12 - M 13**), we modeled a combination of individual and coupling effects on climate change mitigation. Except for RNEW, the coefficients on GHG ~ *f*[GDPPC, GOVERN, RNEW, FDI, RNEW*GOVERN] in model 12 are positive. While FDI and RNEW*GOVERN are statistically insignificant, a percentage increase in income level aggravates climate change by 0.60% ($p < 0.01$). Meaning that an increase in income level negates environmental sustainability. Similarly, except RNEW, GHG ~ *f*[GDPPC, RNEW, FDI, GOVERN, RNEW*FDI] revealed positive coefficients in model 13. Renewable energy consumption and the interactive effect of FDI and renewable energy consumption are statistically significant at 5% level. Empirically, while a 1% increase in the interactive effect of FDI and the renewable energy consumption worsens climate change by 34.33% ($p < 0.05$), renewable energy consumption reduces climate change by 35.32% ($p < 0.1$).

5. Discussion

Highlights from the dynamic heterogeneous parameter models reveal the following with policy implications. The singular effect (**M 3**) of income level appears to produce nearly the same significant coefficient (i.e. 0.60–0.61%) as the composite models (**M 1** and **M 12**). Growth in income has a positive causal effect on greenhouse gas emissions, thus, confirming the scale effect hypothesis. The scale effect posits that developing economies based on energy-intensive industries — agriculture and forestry products, chemicals and primary metals exacerbate environmental pollution at the early stages of economic development —due to over-exploitation of natural resources and energy supply to meet the growing demand. Income level was found to play a domineering role in the coupling effect with renewable energy consumption, FDI and governance on climate change. While FDI and governance were directly proportional to income level, renewable energy consumption was indirectly proportional (see Appendix D). These findings are supported by Liobikienė and Butkus (2019) who found a similar trend for 147 countries. Meaning that the positive coupling effect of renewable energy-induced income level on climate change may be due to the negative correlation between renewable energy consumption and income level. Hence, the scale effect of income level overshadows the technique effect of renewable energy consumption in energy-intensive industries and agrarian-based economies. Another possible explanation of renewable energy-induced-income-attributable impact on climate change can be attributed to air pollution from the share of unsustainable use of solid biomass (specifically, charcoal, woodfuel and agricultural waste). It is estimated that over 90% of households in Sub-Saharan Africa rely on woodfuel, agricultural waste, and charcoal for cooking and heating purposes (IEA, 2017). Noxious fumes due to the burning of fuelwood, waste, and charcoal have been linked to the over 2.8 million annual premature deaths (Sarkodie et al., 2019).

The evidence-based results show that decoupling renewable energy consumption from economic development is conducive for mitigating climate change and its impacts. Supporting our empirical results, conscious effort of replacing fossil fuels with renewable energy technologies led to a reduction in energy consumption—elucidating a drop in CO_2 emissions in developed countries (Le Quéré et al., 2019). However, the interactive effect of renewable energy consumption and other regressors (income level, FDI and governance) heightens climate change. The technique effect of renewable energy consumption and governance on climate change mitigation was invalid for the following reasons. According to York and Bell (2019), expansion of renewable energy in a country's energy portfolio without transition from fossil fuels doesn't have much impact on environmental sustainability. However, strong government policies that limit the extraction of fossil fuel energy sources and transition from coal, gas, and oil to clean and renewable energy technologies decline the consequences of conventional fuels on climate change. It appears that the results of the coupling effect of renewable energy are not farfetched, as drivers of renewable energy consumption differ across countries and vary with time. While access to energy is the main driver of renewable energy consumption in developing countries like Africa, Asia and among others, renewable energy consumption in developed countries is driven by energy security and environmental sustainability concerns (Edenhofer et al., 2011). The magnitude of the technique effect of renewable energy consumption from a policy perspective is dependent on its share in the energy portfolio, technological innovation for its production, country-specific policy instruments, cost of production and purchase price compared to fossil fuels (Owusu and Asumadu, 2016).

The composition effect of foreign direct investment posits that the share of FDI in economic development aids in the structural transformation of the economy — which has an either positive or negative impact on environmental pollution — due to the comparative advantage of production. Contrary to previous studies [Mert and Bölük (2016); Paramati et al. (2017)] that validated the pollution halo hypothesis, the positive impact of FDI-attributable climate change affirms the pollution haven hypothesis in Sub-Saharan Africa. The basic premise is that pollution-intensive industries from developed countries with more restrictive environmental standards will move to poor developing countries with laxed environmental policies (Sarkodie and Strezov, 2019). Developing countries with laxed environmental policies will have a comparative advantage in attracting more FDI inflows and with the likelihood of snowballing environmental pollution (Siebert, 1977). Developing countries are then said to have become pollution havens as they become production centers for transferred pollution from developed countries. However, these organizations in polluting countries are expected to lead to specialization and industrialization and more importantly, improvement in income levels of host countries (Dean, 2002). Thus, the foundation of the pollution haven hypothesis is that the demand for environmental quality is income-sensitive (Walter and Ugelow, 1979) —as demonstrated in the positive correlation between FDI inflows and growth in income (see Appendix D). In contrast, due to the less volatility of foreign direct investment inflows, its share to a country's economic growth serves as the most important source of external financing towards achieving private sector growth and the sustainable development goals (DiSano, 2002). Thus, FDI-induced clean and modern technological transfer, improved management, labor, and technical skills are essential to achieving environmental sustainability in Sub-Saharan Africa.

The study demonstrates that both coupling and decoupling effect of governance increases climate change. This outcome is contrary to our *a priori* expectation — a negative causal effect of governance on GHG emissions was required to validate the technique effect hypothesis. A possible explanation may be that governance cannot have a standalone impact on climate change mitigation without income growth and responsive citizens — this is evidenced in the positive correlation between governance and all data series excluding renewable energy consumption (see Appendix D). Another possible reason for the ineffective coupling of both governance and the renewable energy consumption is that the technique effect is only valid in high-income countries that designate more resources for research and development, innovation, value addition, and technological advancement to address vintage technologies, energy security issues and environmental concerns.

Policy recommendations: Though renewable energy consumption was expected to increase with growth in income, foreign direct investment, and governance, however, an inverse proportion was observed. This explains why the technique effect of renewable energy was invalid, thus, the pollution-reduction effect of renewable energy consumption can be effective when decoupled from economic growth. Renewable energy technologies can only thrive in Africa with strong and effective governance along with modern transfer of innovation, science, and technology. The study demonstrates that climate change mitigation requires a multifaceted approach, hence, the following recommendations are made:

- Government action towards economic structural change through decarbonization and energy efficiency is essential to curtail emissions.
- Government effort to improving environmental quality requires fossil fuel switching and diversification of the energy mix with clean and renewable energy technologies.
- Improving institutional quality is a key component of enhanced political will towards climate change mitigation.
- Global partnership with developed economies through external funding is crucial to achieving sustainable development goals.

6. Conclusion

The economic development — environmental pollution nexus is complex, thus, unpredictable from *a priori* expectation. The notion is valid for the relationships between renewable energy, FDI, per Capita GDP, and governance on GHG emissions. However, changes in economic-induced environmental pollution can be scrutinized by decomposing them into three forms namely scale, composition and technique effects. Thus, this study assessed the individual, combined and interactive impact of socioeconomic variables on environmental indicators. Using a data series from 1990 to 2017 in 47 Sub-Saharan African countries, we employed dynamic heterogeneous parameter models to develop 13 conceptual tools useful for policy formulation.

The empirical results reveal that growth in income exacerbates pollution intensities, which in turn affects climate change and its impact. The increasing level of pollution intensities can be attributed to production and expansion than environmental challenges, hence, environmental policies and regulations are laxed to favor foreign investments. This explains why both governance and foreign direct investment had a positive impact on climate change. The nexus between FDI inflows and climate change confirmed the pollution haven hypothesis. Thus, the transfer of '*dirty*' goods from developed countries negates environmental sustainability and exposes developing countries — especially Africa to climate change vulnerability. The presence of renewable energy consumption was found to decline the burden of climate change, yet, coupling with income level, governance, and FDI inflows was found to upsurge climate change.

Due to the localized characteristic of renewable energy, future studies should aim at assessing the scope of the study via a country-specific assessment for effective policy recommendation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Samuel Asumadu Sarkodie: Conceptualization, Formal analysis, Writing - original draft. **Samuel Adams:** Writing - original draft. **Thomas Leirvik:** Supervision, Writing - review & editing.

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Appendix A. Supplementary data

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