Transnational Corporations Review 15 (2023) 59–68

Contents lists available at ScienceDirect

Transnational Corporations Review

journal homepage: www.journals.elsevier.com/transnational-corporations-review

Research Article

Foreign direct investment, gross domestic product and carbon dioxide emission in sub-Saharan Africa: A disaggregated analysis

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ARTICLE INFO

Keywords:
FDI
Economic growth
Carbon dioxide emission
Sub-Saharan Africa

ABSTRACT

This paper investigates the heterogeneous effect of sector-level foreign direct investment on carbon dioxide (CO_2) emissions in 36 sampled SSA countries from 1990 to 2016. By using the system GMM estimation technique, the study reveals that industry FDI increases CO_2 emissions validating the pollution haven hypothesis while Agric FDI and service FDI reduce CO_2 emissions. In general, a U shape hypothesis holds for Agric FDI and CO_2 emissions, but an inverted U shape for industry FDI and Industry CO_2 emissions and a linear and negative relationship between services FDI and services CO_2 emissions. Thus, there is a need to evaluate the environmental cost of investment in the industrial sector before granting foreign investors a permit to operate. In addition, there should be specific policies to attract FDI into the agriculture and services sectors to benefit from the positive spillover effect of transfers of cleaner technology.

1. Introduction

The past couple of decades had witnessed an expansion of many economies with various economic and social reforms resulting in the influx of FDI and economic growth. To fuel economic activity, there has been an increase in energy consumption resulting in the buildup of CO_2 emissions. Consequently, the increase in FDI, economic growth, and increased in energy demand resulted in the accumulation of CO_2 the main greenhouse gas GHG responsible for climate change (Hoffmann et al., 2005; Kivyiro and Arminen, 2014). GHGs can cause the gradual washing of sandy beaches, increase in the sea level, drought and floods as well as physical and psychological problems in humans (Douglas et al., 2000; Hitam and Borham, 2012). The Kyoto protocol and the Copenhagen accord are some of the efforts aimed at attenuating the concentration of GHGs in the atmosphere. Notwithstanding these measures, the concentration of GHGs especially CO_2 has been rising. Fig. 1 shows the trends in FDI, per capita CO_2 emissions, and natural resource depletion in Sub-Saharan Africa.

From Fig. 1, the amount of average annual FDI as a percent of GDP in SSA stood at 1.23 percent in the early 1990s and this rose to 2.59 percent during the 1995–1999 period. However, it declined to 2.17 percent of GDP during the period 2000–2004 and increased to 4.9 percent of GDP during the 2010–2014 period. On average, CO_2 emissions in metric tons per capita also rose from 1.17 in the early 1990s to 1.26 during 2005–2009 and increased to 1.28 metric tons per capita in 2010–2014. Over the same period, natural resource depletion also increased from 6.77 percent of gross national income (GNI) in the early 1990s to 8.52 in the early 2000s. It increased further to 11.14 percent of GNI during 2010–2014.

In general, FDI may generate direct capital financing and positive spillover effects; and consequently spurs economic growth through the transfer of technology and; the introduction of new methods of production and managerial expertise (Lee, 2013; Omri and Kahouli, 2014). However, the growth propelled by FDI comes at the expense of the environment in the form of GHG emissions, deforestation, and loss of biodiversity (Mabey &McNally, 1999; He, 2006). The reason is that in the absence of adequate absorptive capacities, developing countries tend to relax environmental regulations to attract FDI known as the pollution haven hypothesis (Copeland and Taylor, 1994; Cole, 2004). Conversely, advanced technology and managerial expertise employed by foreign firms may improve environmental quality in the host country known as the pollution halo hypothesis (Eskeland and Harrison, 2003; Tamazian et al., 2009). Empirical studies examining the pollution haven hypothesis and pollution halo hypothesis have generated divergent results. While some studies find evidence in favor of the pollution haven hypothesis (Hitam and Borhand, 2012; Shahbaz et al., 2015), other studies support the pollution halo hypothesis (Lee, 2013; Asghari, 2013).

The quest for industrialization has precipitated intense debate regarding the relationship between economic growth and the environment in the past few decades. Empirical evidence suggests that the

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https://doi.org/10.1016/j.tncr.2023.01.001
Received 29 December 2021; Received in revised form 18 November 2022; Accepted 24 January 2023
Available online 17 November 2023

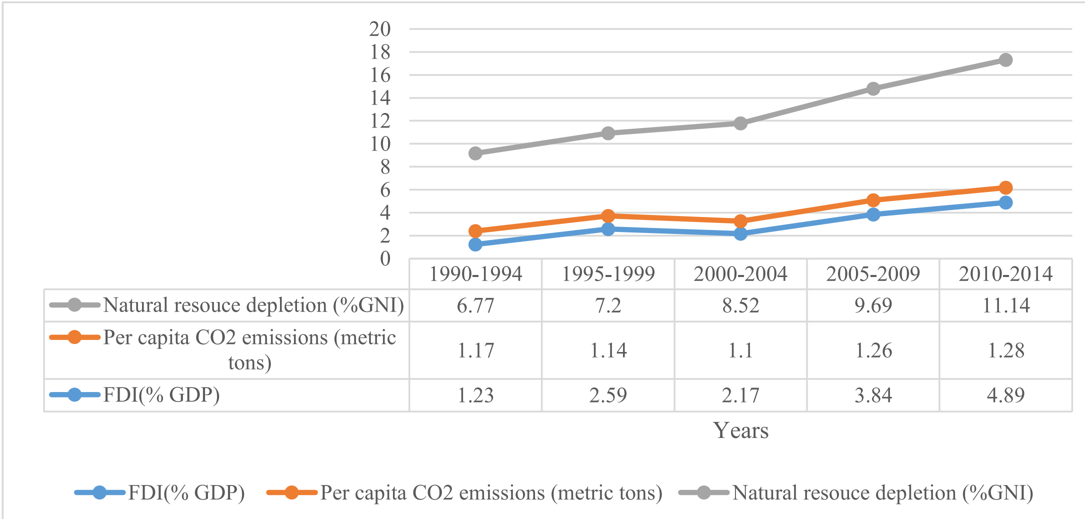

Fig. 1. Trends in Foreign Direct Investment, Per capita CO_2 Emissions and Natural Resource Depletion in Sub-Saharan Africa.
Source: (World Development Indicators, 2016).

environmental pollution curve moves upward initially, attains a maximum point, and falls as the economy develops. This inverted U-shaped relationship is known as the environmental Kuznet curve (Grossman and Krueger, 1995; Rothman, 1998). Indeed, FDI has an impact on economic growth and energy consumption and can lower energy demand when foreign firms adopt advanced methods of production (Hamdi et al., 2014). Previous studies also link the increase in per capita income or energy demand due to FDI with CO_2 emissions (Shahbaz et al., 2013; Solarin and Shahbaz, 2013).

The limitation of previous studies of FDI and carbon dioxide emissions is the use of aggregate FDI and the assessment of emissions from all sectors combined using carbon dioxide emission as an aggregate proxy for pollution (Kivyiro and Arminen, 2014; Shahbaz et al., 2015). Undoubtedly, the activities of foreign firms in different sectors may contribute unequally to carbon dioxide emissions. Consequently, the use of composite FDI could conceal the sectoral effect of FDI on the environment. In addition, no distinction was made between domestic and foreign investment to clarify pollution sources in previous studies. Thus, the objective of the study is to examine the heterogeneous effect of sector-level foreign direct investment on carbon dioxide (CO_2) emissions in SSA. The study contributes to the existing literature in the following ways: Firstly, the study disaggregates both FDI and CO_2 into different sectors and examines how FDI inflows into a specific sector generate CO_2 emissions in that sector. Secondly, we include domestic investment to distinguish between domestic and foreign sources of pollution. Thirdly, the study tests the validity of the environmental Kuznet curve for the various sectors.

The rest of the paper is presented as follows: Section 2 presents literature on FDI, GDP, and carbon dioxide in SSA. The methodology and data are discussed in section 3. The estimation results and discussion are presented in Section 4 while Section 5 draws conclusions and offers policy prescriptions from the results. From a policy perspective, understanding the linkages between sectoral FDI and CO_2 emissions is key to designing and implementing sector-specific environmental policies aimed at attenuating GHGs emissions in SSA.

2. Literature review

Previous studies linking FDI, GDP, and the environment can be classified into three groups. The first group investigates the energy-growth nexus, the second group examines the growth-environment nexus and the third group incorporates all the variables into a single multivariate framework and includes FDI as another determinant of the environment. In this section, we examine the evolution of the relationship between FDI and CO_2 emission focusing on the different strands of literature that have been investigated.

2.1. Energy – growth nexus

Theoretically, the demand for energy to fuel economic activities rises with economic growth. This implies that economic development is accompanied by increased energy consumption. Efficiency in energy use also requires a high level of economic development. Thus, the relationship between energy and growth could be either positive or negative. However, *a priori*, we expect the relationship between the two variables to be positive.

Since the pioneering work of Kraft and Kraft (1978) who investigate the relationship between energy and economic growth in the USA, scores of studies have emerged with diverse conclusions (Ouédraogo, 2010; Saidi and Hammami, 2015). The first strand of literature comprises individual country studies (Akinlo, 2008; Ouédraogo, 2010). The second strand employs a cross-country panel data approach (Ozturk, 2010; Saidi and Hammami, 2015). The results from these studies show that energy consumption exerts either a positive, negative or no effect on growth.

2.2. Growth-environment nexus

The second nexus is strongly connected to the verification of the existence of the Environmental Kuznets Curve (EKC) hypothesis. The EKC hypothesis postulates that environmental pollution rises with income but begins to fall as rising income exceeds a certain threshold. Thus, the relationship between income and pollution is inverted U-shaped. Several subsequent studies have examine the growth-environment nexus following the seminal work of Grossman and Krueger (1991). These studies include individual country studies (Freitas and Kaneko, 2011; Adom et al., 2012), as well as cross-country panel studies (Narayan and Narayan, 2010; Jaunky, 2011). Some of the proxies used in these studies as environmental indicators are CO_2, particulate matter (PM10) and sulphur dioxide (SO_2) (De Freitas and Kaneko, 2011; Orubu and Omotor, 2011). While some of the studies find evidence in support of EKC (Narayan &Narayan, 2010; Orubu and Omotor, 2011) others find no evidence in support of the EKC (Boopen and Vinesh, 2011; Alam, 2015).

2.3. Foreign direct investment - growth - environment nexus

The third category of the literature incorporates all the nexuses into a single multivariate framework and identifies FDI as a crucial determinant of the environment based on the pollution haven and pollution halo hypothesis. The pollution haven hypothesis postulates that FDI inflows are at a cost to the environment due to lax environmental regulations in the host country. The pollution halo hypothesis, however, states that foreign firms use environmentally friendly technology which improves the quality of the environment in the host country. Scores of studies have been carried out to test these hypotheses. Some of these studies are country-specific studies (Kivyiro and Arminen, 2014; Keho, 2016) while some are cross-country panel studies (Asghari, 2013; Aboagye and Nketiah-Amponsah, 2016). This category of the literature employs CO_2, Sulfur dioxide (SO_2), Biochemical Oxygen Demand (BOD), particulate matter, forest depletion, and natural resource depletion as basic indicators of the environment. In general, results are mixed. Some studies lend support to the pollution haven hypothesis (Hitam and Borhand, 2012; Shahbaz et al., 2015) and others claim evidence in support of the pollution halo hypothesis (Lee, 2013; Asghari, 2013).

Several studies have also examine sector specific effect of either FDI or growth on the environment (Paul and Bhattacharya, 2004; Jorgenson, 2007; Kumbaroglu, 2011; Alam, 2015; Doytch and Uctum, 2016). For instance, Jorgenson (2007) investigates the effect of investment in agriculture on CO_2 emissions in less-developed countries from 1980 to 1999. By using panel regression analyses of 35 less developed countries, the study shows that the use of tractors and the scale of production in the agriculture sector contribute to the rise of CO_2 emissions. Doytch and Uctum (2016) also examine the effect of FDI on the environment using the GMM estimation technique. The authors find that investments in manufacturing and non-financial services hurt the environment. The study further shows that FDI improves the environment in high-income countries across industries, but hurts the environment in low-income countries.

Using decomposition analysis, Paul and Bhattacharya (2004) examine how changes in energy consumption and economic growth affect CO_2 emissions in India. The study shows that economic growth is a major contributor to pollution in all sectors. The industrial and transport sectors show a decline in CO_2 emissions as a result of improved energy efficiency and fuel switching. However, energy intensity exerts no significant effect on the agricultural sector. Kumbaroglu (2011) examines the effect of energy intensity and growth across various sectors in Turkey from 1990 to 2007. The author finds that growth was the main driver of emissions in the transport, electricity, and manufacturing sectors but has no effect on the agriculture and household sectors. Alam (2015) investigates the effect of value added in GDP from agriculture, manufacturing, and services on CO_2 emissions in South Asia from 1972 to 2010. The result indicates that agriculture value added in GDP improves the environment whiles value added from industry and services pollutes the environment.

The existing studies on foreign direct investment - growth - environment nexus arrived at different conclusions. The lack of unanimity in various studies could be attributed to the dissimilarities in scope, estimation techniques, methodologies, proxies, and issues relating to data. It is obvious that the literature lacks sector specific analyses of the effect of FDI on the environment in SSA. In SSA, data on FDI is in aggregate form while FDI's effect on the environment may be sector specific. Thus, the use of aggregate FDI could mask the sectoral effect of FDI on the environment. In addition, previous studies have used the composite measure of CO_2 instead of decomposing into various sectors. Moreover, existing studies made no distinction between domestic and foreign investment to clarify pollution sources.

3. Model and econometric methodology

3.1. Model

The present study used a dynamic panel estimation technique to investigate the effect of sectoral FDI in agriculture, industry, and services on carbon dioxide emissions for 36 sampled SSA countries from 1990 to 2016, while controlling for the EKC. The system GMM is the dynamic panel estimation technique employed in this study. Following Doytch and Uctum (2016), the tested dynamic empirical model to determine the heterogeneous effect of sector-specific FDI on the environment is specified as:

$$\ln CO^{j}_{2it} = \alpha_0 + \alpha_1 \ln CO^{j}_{2it-1} + \alpha_2 \ln [(FDI)]^{k}_{it} + \alpha_3 \ln [(FDI^{2}_{it})]^{\;k} + \alpha_4 \ln[(GDP)]^{m}_{it} + \alpha_5 \ln [(DI_{it}] + \alpha_6 \ln[(INT)]^{n}_{it} + \alpha_7 \ln [(IMP_{it}] + \alpha_8 \ln [(EXP_{it}] + \alpha_9 \ln [(FMD_{it}] + \alpha_{10} \ln [(URB_{it}] + \nu_{it}$$

Where

The superscripts j, k and m denotes an index for total, agricultural, industry and services CO_2, FDI and output respectively. The superscript n represents an index of the interactive term (INT) which is a product between sector specific FDI and domestic investment DI for total, agricultural, industry and services respectively; IMP represents import; EXP represents export; FMD is financial market development and URB represents urbanization.

$\nu_{it} = \mu_{it} + \varepsilon_{it}$, where μ_{it} is an idiosyncratic country specific effect and the error terms ε_{it} are such that ε_{it} $ii(0, \sigma^2_{\varepsilon})$, $\mu_{it} \tilde{} ii\,(0, \sigma^2_{\mu})$. α_1 is a scalar such that $|\alpha_1| < 1$; $i = 1,2,3, \ldots, N$. denotes an index of individual selected countries, t = 1,2,3.T is an index of time periods. The unobservable country-specific effect μ_{it} and the error term ε_{it} are not correlated. The $\alpha' s$ denotes the unknown parameters of the explanatory variables.

According to Hoffmann et al. (2005) and Kivyiro and Arminen (2014) accumulation of CO_2 is a major cause of climate change and it is correlated with other GHGs emissions such as sulfur dioxide and nitrous dioxide. Besides, several studies (Talukdar and Meiser, 2001; Kivyiro and Arminen, 2014) have used per capita CO_2 emission (in metric tons) due to the availability of data on carbon dioxide. Therefore, CO_2 is used as a dependent variable.

FDI per capita is used to test its impact on the environment. Previous studies have indicated that initially, FDI pollutes the environment during economic growth and at a certain turning point FDI begins to improve the environment as the country develops. Thus, the relationship between FDI and the environment is non-linear known as an inverted U-shaped EKC. Following recent studies (Eskeland and Harrison, 2003; Aliyu, 2005; Shahbaz et al., 2015) the squared term of FDI was included in the regression equation to examine the non-linear relationship between FDI and CO_2 emission. Thus, both are included to test the existence or otherwise of the EKC. Therefore, it is expected that the sign is positive and negative.

In line with previous studies, GDP which denotes gross domestic product is measured by per capita GDP ($ USD) (Kivyiro and Arminen, 2014; Shahbaz et al., 2015). The reason is that the scale effect is part of the expected FDI effect on the environment. Thus, the sign of GDP is expected to be positive since growth rises with environmental degradation at the initial stage of development.

The source of the dataset is the World development indicators (2016) produced by the World Bank. Table 1 below presents the description, measurement of data, and the list of sampled countries is reported in Appendix 1. (see Appendix).

3.2. Econometric methodology

The study presents the econometric methodology under the following sub-themes: the panel unit root, the panel cointegration, and the system Generalized Method of Moments (GMM).

In general, most econometric variables demonstrate stochastic trends that produce spurious regression. Thus, investigating the long–run relationship between economic growth and it drivers calls for the examination of the stationarity properties of the series. There are many unit root tests available for testing the unit root properties of variables. In this paper, we use the Fisher P–P test because, unlike other methods, it does not rely on different lag lengths in each ADF estimation. It can also be applied whether the panel is balanced or unbalanced. Moreover, it can be used on panels with missing data points. The null hypothesis is that the variables are stationary. The alternative hypothesis is that the variables are not stationary. The results of the panel unit root test are presented in Table 2. Based on the Fisher P–P Chi-square unit root test which is

Table 1
Description, measurement and expected sign of variables.

Variable	Notation/Expected Sign	Description and Sources
Dependent Variables Carbon Dioxide (Metric tons per capita)	$lnCO_2$	Carbon dioxide emissions are generated from fossil fuels and the manufacture of cement. It comprises carbon generated during the consumption of solid, liquid, and gas fuels and gas flaring. Source: World Development Indicators (WDI)
Agricultural methane emissions (thousand metric tons of CO_2 equivalent)	$ln\mathrm{ACO_2}$	These are emissions produced from savannah and agricultural waste burning. It is also generated during rice production of animal and animal waste. Source: Author's computation based on WDI
Industrial carbon dioxide emission CO_2 emissions (% of total fuel combustion)	$ln\mathrm{ICO_2}$	Consists of total carbon dioxide generated from construction, manufacturing, electricity and heat production. Source: Author's computation based on WDI.
Services carbon dioxide emission (% of total fuel combustion)		Consists of total carbon dioxide produced from transport, residential buildings and commercial and public services an,d other sectors. Source: Author's computation based on WDI
Explanatory Variables		
Lagged Dependent Variable	$j_{lnCO2t-1}$	Immediate past value of the dependent variable. Source: Author's computation based on data from WDI
Foreign Direct Investment per capita (% GDP)	$lnFDI^{+/-}$	FDI comprises total equity capital as well as reinvestment of profits and both short-term and long-term capital to obtain management interest in the long run usually in an enterprise producing abroad expressed as a proportion of nominal GDP divided by population Source: (World Development Indicators [WDI])
FDI per capita squared (% GDP)	$ln\mathrm{FDI}^{2\ +/-}$	Quadratic term of FDI obtained by squaring FDI. Source: Author's computation based on WDI.
Agric FDI per capita (% GDP)	$lnAFDI^{+/-}$	Comprises FDI in livestock and crop production as well as fishing hunting and forestry. Source: Author's computation based on WDI
Industry FDI per capita (% FDI)	$lnIFDI^{+/-}$	Consist of FDI in mining, quarrying and petroleum, manufacturing, electricity, gas, construction and water and sewerage Source: Author's computation based on WDI
Service FDI per capita (% GDP)	$lnSFDI^{+/-}$	Service FDI consists of flows in retail and wholesale trade in intangibles such as education, health care, transport, finance and government services. It also includes hotels and restaurants and personal services. Total service FDI is divided by total population and expressed as a percentage of GDP. Source: Author's computation based on WDI.
Value added (constant 2010 U S. dollars)		Value added is the difference between a finished product and the raw materials used in its production. It includes depreciation but does not cater for non-market transactions such as depletion and degradation of natural resources. Source WDI
Agric Value added	$lnAVA+$	
Industry Value added	$lnIVA+$	
Service Value added	$lnSVA+$	
Gross domestic product per capita (Constant, 2010 US$)	$lnGDP^{+}$	GDP per capita refers to the summation of gross value added by all producers in the economy plus net indirect taxes. GDP per capita is obtained by Gross Domestic Product divided by the population. Source: WDI
Domestic Investment (% GDP)	$lnDI^{+/-}$	Gross fixed capital formation could be considered as the total investment in a country. Inward FDI is an investment by foreign firms. Thus, the difference between GFCF and FDI as a share of GDP becomes a measure of domestic investment (Agrawal, 2000; Wang, 2009). Source: WDI
Export of goods and services (% GDP)	$lnEXP^{+}$	This is the value of all goods and services supplied by a country to the rest of the world. These comprise insurance, freight, travel, license fees, merchandise, transport, freight, and other services such as personal, financial, business, construction, information, and government services. Compensation of employees, transfer payments and investment income are excluded. Source WDI
Import of goods and services (% GDP)	$lnIMP^{+}$	This is the value of all goods and services acquired by a country from the rest of the world. These comprise insurance, freight, travel, license fees, merchandise, transport, freight, and other services such as personal, financial, business, construction, information and government services. Compensation of employees, transfer payments and investment income are excluded. Source: WDI
Urbanization (% of total)	$lnURB^{+}$	Urbanization refers to the growth of population in towns and cities as evaluated by national statistical offices. Data obtained are adjusted by the United Nations. Source: WDI
Financial Market Development Broad money (%GDP)	$lnFMD^{+/-}$	Broad money is the sum of currency with the non-bank public, demand deposits excluding those with the Central Bank, foreign currency deposits, savings and time deposits, bank and traveler's checks, deposits of resident sectors other than government, and other securities such as commercial paper and certificates of deposit. Source: WDI
Interactive term	$lnINT^{+/-}$	The interactive term (INT) is the product of FDI and domestic investment (DI) Source: Author's computation based on WDI.

NB. *The a priori sign is indicated by ± in the notation Column.*
ln is the natural logs of the variables

deemed ideal for both balanced and unbalanced panel data, it is established that all the variables are stationary at levels. To check for the robustness of the results, ADF Fisher chi-square and the IPS were carried out and both tests confirmed the stationarity of the variables at levels.

3.2.1. Panel cointegration

Cointegration tests are carried out to test whether a long–run relationship exists between variables. The methods used to test panel cointegration are Kao (1999), Pedroni (1991), and Maddala and Wu (1999) or Fisher test. The cointegration test addresses issues of endogeneity, slope heterogeneity, and omitted variables which are often encountered in econometric models. In addition, panel cointegration techniques can be applied to data with short periods, unlike time-series techniques. In this study, the panel cointegration test between CO_2 and the explanatory variables is carried out using the Kao residual cointegration test and Johansen Fisher panel cointegration test. The results are presented in Table 3. The Kao test demonstrates panel cointegration at a 1 % level of significance. The results are consistent: Johansen Fisher panel cointegration test (both trace and Max-Eigen statistics) demonstrates the existence of cointegration relations between the variables for the two models. In general, there is the existence of panel cointegration between the variables.

Following the establishment of the long relationship between the variables, we proceed to estimate the associated long-run elasticities

Table 2
The panel unit root test results.

Methods	Variables	lnCO2	lnFDI	lnGDP	lnDOI	lnIMP	lnEXP	lnFMD	lnURB
PP-Fisher chi square	[Level]	443.95	499.72	390.77	434.01	558.83	536.14	440.48	579.47
	[p-value]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
ADF Fisher chi square	[Level]	386.6	415.194	356.277	391.833	521.842	488.856	385.116	511.047
	[p-value]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
IPSw-stat	[level]	−15.71	−17.46	−13.32	−16.79	−21.63	−20.24	−15.46	−16.52
	[p-value]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]

Table 3
Panel cointegration test results.

1		Kao Residual Cointegration Test			
ADF		t-Statistic −9.322168			p-value. 0.000
2				Johansen Fisher Panel Cointegration Test	
Hypothesized No. of CE(s)	Fisher Statistic (Trace test)	Fisher Statistic p-value	(Max-Eigenvalue)	p-value	
r = 0	518.5	0.000	554.7	0.000	
r ≤ 1	488.5	0.000	212.9	0.000	
r ≤ 2	255.6	0.000	142.5	0.000	
r ≤ 3	149.8	0.000	69.85	0.001	
r ≤ 4	92.85	0.000	40.86	0.266	
r ≤ 5	66.79	0.001	24.79	0.921	
r ≤ 6	61.57	0.005	26.12	0.887	

using the GMM estimation technique. The GMM estimation technique is used for several reasons. First, the use of the Ordinary Least Squares (OLS) method in the dynamic panel may result in bias and inconsistent estimates due to the correlation between the lagged dependent variable and the error term (Abid and Sekrafi, 2020; Arellano and Bond, 1991). Second, panel data is preferred to cross-sectional data which also generates bias estimates because of the correlation between the lagged dependent variable and the error term which disappears in samples with large time-dimension but does not disappear with time-averaging. Thus, the correlation between the lagged dependent variable and the error term indicates that the true underlying structure has a dynamic nature and time-averaging cross-sectional analysis may introduce a bias that cannot be addressed by controlling for fixed effects. Consequently, the dynamic relationship between FDI, growth, and CO_2 emissions in this study was carried out using the GMM estimation technique.

There are three variants of the GMM estimation technique. Arellano and Bond (1991) recommended the difference GMM; Arellano and Bover (1995) suggested the deviation GMM and Blundell and Bond (1998) proposed the system GMM. The choice of the GMM estimation technique is based on the fact that it addresses econometric problems prevalent in macro-panel models such as endogeneity, serial correlation, and cross-sectional interdependence (Arellano and Bond, 1991).

The variance of the estimates obtained from the difference GMM may increase asymptotically producing bias coefficients. In addition, the difference GMM and the deviation GMM use information provided in differences only. To address these limitations, Blundell and Bond (1998) suggested an estimation technique with a system of regressions in levels and differences. The lagged levels of the explanatory variables are used as instruments in the regression in differences while the lagged differences of explanatory variables are used as instruments in the levels regression. These instruments are deemed appropriate based on the assumption that though level variables might correlate with country-specific effects, variables in differences and the country-specific effect would not correlate.

The system GMM estimator is efficient because though the country-specific effect might correlate with level variables, such correlations are absent between variables in differences and the country-specific effect. Furthermore, the system GMM estimator generates a standard covariant matrix that is robust to heteroscedasticity and autocorrelation. However, the weakness of the GMM estimator is instrument proliferation in which several instruments may be individually significant, but insignificant as a group in infinite samples because the instruments overfit the endogenous variables.

The Sargan test and Arellano-bond test are used to test for the consistency of the system GMM estimator. The Sargan test is used to test for the joint significance of the instruments. The null hypothesis is that the instruments used as a group are exogenous versus the alternative hypothesis is that the instruments are not exogenous. The model is supported when the null hypothesis is rejected. The Arellano-bond test for second-order serial correlation examines the null hypothesis that the error term is not serially correlated and is applied to the differenced residuals. The model is supported when the null hypothesis is rejected.

4. Results and discussion

The empirical results are presented in this section. Before the estimation of the long run, elasticities using the system GMM estimation technique, the correlation, and descriptive statistics were computed (see Appendix 2 & 3). We then proceed to estimate the associated long-run elasticities employing the GMM estimation technique and the result is presented in Table 4. Column (1) presents the impact of total FDI per capita on total CO_2 emissions. Column (2) reports the impact of agricultural FDI per capita on methane emissions (thousand metric tons of CO_2 equivalent) from the agricultural sector; column (3) shows the impact of industry FDI per capita on CO_2 emission from industry and column (4) displays the impact of service FDI per capita on CO_2 emission from the services sector.

From Table 4, the coefficient of the lagged dependent variable is positive. This means that the present level of CO_2 increases the future level of CO_2. This indicates a strong persistent effect underlying the cumulative nature of CO_2 in the region. Particularly, in column [1], a 1 % increase in the lagged dependent variable results in a 0.343 increase in CO_2 emission. The coefficient of FDI per capita is negative and statistically significant meaning FDI per capita reduces aggregate CO_2 emissions in the 36 sampled SSA countries. Specifically, a 1 % increase in FDI per capita reduces aggregate CO_2 emissions by 0.192 validating the pollution halo effect hypothesis. This result is consistent with that of Zhu et al. (2016) in Singapore, Thailand, the Philippines, Indonesia, and Malaysia. In contrast, Hitam and Borhand (2012) and Balibey (2015) find that FDI is detrimental to the environment validating the pollution haven

Table 4
Panel regression results.

Dep. Variables:	lnCO_2	lnACO_2		lnICO_2		lnSCO_2	
TOTAL [1]		AGRIC [2]		INDUSTRY [3]		SERVICE [4]	
ln CO_2t-1	0.343***	lnA CO_2t-1	0.237***	lnI CO_2t-1	−0.062	lnS CO_2t-1	0.343***
	[0.072]		[0.060]		[0.051]		[0.082]
lnFDI	−0.192***	lnAFDI	−0.561*	lnIFDI	2.591*	lnSFDI	−0.452*
	[0.068]		[0.293]		[1.450]	[0.246]	
lnFDI^2	0.007**	lnAFDI^2	0.006*	lnIFDI2	−0.028*	lnSFDI2	−0.005*
	[0.003]		[0.003]		[0.006]		[0.003]
lnGDP	0.005	lnAVA	−0.079	lnIVA	0.195	lnSVA	−0.079
	[0.054]		[0.081]		[0.137]		[0.079]
ln DI	−0.143**	lnDI	0.602	lnDI	−3.429	lnDI	−0.438*
	[0.063]		[0.638]		[4.125]		[0.219]
ln INT	0.011***	lnINT	−0.009	lnINT	0.067	lnINT	0.009**
	[0.004]		[0.012]		[0.080]		[0.004]
lnIMP	0.100*	lnIMP	−0.011	lnIMP	−0.136	lnIMP	0.164*
	[0.054]		[0.069]		[0.119]		[0.068]
lnEXP	−0.032	lnEXP	−0.036	lnEXP	−0.198	lnEXP	0.0013
	[0.059]		[0.066]		[0.227]		[0.067]
lnFMD	0.110	lnFMD	0.0347	lnFMD	0.343	lnFMD	0.136**
	[0.053]		[0.078]		[0.264]		[0.064]
ln URB	0.010	lnURB	0.0311*	lnURB	0.075***	lnURB	0.022
	[0.017]		[0.016]		[0.033]		[0.016]
Constant	17.331***	Constant	42.361***	Constant	−44.576	Constant	25.575***
	[4.054]		[9.166]		[42.779]		[9.068]
Observations	747	501		372		676	
No. of countries	36	35		19		35	
AR (1), p-value	0.000	0.001		0.052		0.000	
AR (2),p-value	0.027	0.247		0.104		0.035	
Sargan test, p-value	0.993	0.985		0.995.		0.724	

//*** denotes statistical significance at 10 %, 5 %, 1 % respectively.* INT = interactive term between sector specific FDI and domestic investment.

hypothesis. The difference in results could be attributed to the stringency of environmental laws.

However, the quadratic term of FDI per capita is positive indicating a U-shaped instead of an inverted U-shaped EKC suggested by Grossman and Krueger (1991). This shows a non-linear relationship between FDI and CO_2 emissions. This implies total FDI initially reduces CO_2 emissions due to the clean technology employed by foreign firms. It is likely that foreign firms may come with energy-efficient technology prevailing in their home country. However, due to lax environmental regulations in the host country and the profit-driven motive of foreign firms, these machinery are not replaced with time. Consequently, these equipment become outdated and less energy efficient and pollute the environment. In contrast to the results obtained in this study, other studies find evidence in support of the EKC (Narayan and Narayan, 2010; Orubu and Omotor, 2011). According to Doytch and Uctum (2016), FDI inflows hurt the environment in developing countries, while it improves environmental quality in developed countries. Thus, the initial level of economic development could account for the differences in these results.

Similarly, in column (1) the coefficient of domestic investment is negative and significant indicating that domestic investment reduces CO_2 emission. Specifically, a 1 % increase in domestic investment reduces CO_2 emission by approximately 0.143. This means that domestic investment improves the quality of the environment. Wang and Jin (2002) reveal that firms that are owned by the state and private individuals generate more pollution than firms owned by the community or foreign firms. This could be attributed to the use of advanced technology by foreign firms which are more energy efficient and community-owned firms also generate less pollution because the cost of production include the cost of pollution which is borne by the firm. Eskeland and Harrison (2003) also indicate that foreign firms are more efficient in energy consumption and the techniques of production are more environmentally friendly compared to domestic firms.

The coefficient of the interactive term between FDI per capita and domestic investment in column (1) is positive and significant. Specifically, a 1 % increase in the interactive term raises the level of CO_2 emission in the region by approximately 0.011. This implies that higher domestic investment drives FDI into dirty industries. This is plausible in that the use of inefficient production technology by domestic firms is an indication of weak enforcement of environmental regulations in the host country that will lead to the influx of dirty industries.

The coefficient of the import variable is positive and significant. Specifically, a 1 % increase in imports increases CO_2 emission by 0.100. This implies that the import of goods and services degrades the environment in the 36 sampled SSA countries. This is plausible in that individuals take advantage of the lax environmental regulation to import carbon-intensive factors of production or goods and services which are not environmentally friendly. For instance in developing countries, some individuals tend to purchase items or acquire properties that make them comfortable whenever their income level rises. Thus, it is common to observe a rise in the purchase of secondhand cars, washing machines, fridges, and air conditioners. In addition, to supplement meager salaries, others purchase over-aged vehicles for commercial purposes. The increase in demand for these items fuels their import. Since most of these items and vehicles are old, they tend to be energy inefficient and pollute the environment.

4.1. Sectoral analysis

In column (2), agricultural FDI per capita exerts a negative effect on CO_2 emission but the coefficient on the quadratic term is positive. This is plausible in that, the obvious feature of agriculture in SSA is the predominance of peasant producer mode of production with few medium and large-scale farmers. The technology applied is rudimentary and represents a very low level of capital intensity. Apart from fertilizer and insecticide which are of little use, there is little use for tractors and other advanced machinery for cultivation. However, with increased mechanization over time and weak regulatory compliance, foreign firms take advantage to pollute the environment.

In contrast, most of the environmental degrading effect of sector-level FDI per capita is generated by investment in the industrial sector. For instance, in column (3), inflows into the industrial sector raise pollution significantly. Specifically, a 1 % increase in industrial FDI per capita

Table 5
Panel fully modified ordinary least square regression results.

Dep. Variables:	$lnCO_2$	$lnACO_2$		InICO2		lnSCO2	
TOTAL [1]		AGRIC [2]		INDUSTRY [3]		SERVICE [4]	
ln CO_2t-1	0.442**	lnA CO_2t-1	0.336**	lnI CO_2t-1	−0.071	lnS CO_2t-1	0.443**
	[0.081]		[0.083]		[0.072]		[0.083]
lnFDI	−0.183**	lnAFDI	−0.554**	lnIFDI	3.541**	lnSFDI	−0.461*
	[0.062]		[0.294]		[1.460]		[0.257]
lnFDI^2	0.009**	lnAFDI2	0.008***	lnIFDI^2	−0.027**	lnSFDI^2	−0.073**
	[0.005]		[0.004]		[0.008]		[0.007]
Controls	*Yes*	*Yes*		*Yes*		*Yes*	
Constant	16.321*	Constant	40.362*	Constant	−46.573	Constant	28.567*
	[3.056]		[7.156]		[40.789]		[8.067]
Observations	747	501		372		676	
No. of countries	36	35		19		35	

*/**/*** denotes statistical significance at 10 %, 5 %, 1 % respectively.

raises CO_2 emission by 2.591 validating the pollution haven hypothesis. This result is consistent with the findings of Shahbaz et al., (2014) and Kivyiro and Arminen (2015) who attribute the rise in CO_2 emissions to the low quality of technology employed in production and lax environmental laws and regulations in SSA.

The rising levels of CO_2 due to industry FDI could be attributed to the increased extraction of natural resources-oil, gas, and minerals in the region. In SSA, the activities of MNEs dominate the extractive industry because mineral extraction is capital-intensive and requires advanced technology. UNCTAD (2007) indicates that in 2005 the share of oil production by foreign firms constitute 57 % of SSA compared to 18 % for Latin America, 11 % for transition economies, and 19 % for all developing countries.

Asiedu (2013) indicates that the increased exploration and production in the region had increased extractive industry's FDI. Consequently, four top oil exporting countries received significant proportions of foreign production from 1992 to 2011. For instance, Equitorial Guinea received 92 %, Angola 74 %, Sudan 64 %, and Nigeria 41 %. The author indicates that over the period 1992–1996 to 2008–2011, the production of oil in Africa expanded by 40 % compared to 15 % in Europe, 24 % in South America, 32 % for Asia, and a fall of 4 % for North America. Moreover, the top four oil-exporting economies' share of production increased from 38 % to 53 %. Sudan and Equitorial Guinea experienced increased production over the period. Thus in SSA, the discovery of oil in Equatorial Guinea in 1990 and Sudan in 1991 was responsible for the increased production.

Thus, the rising levels of CO_2 in the region could be linked to the activities of oil and mining firms in the region. For example, the blasting of rocks during mineral extraction and the high levels of energy consumption by heavy equipment during oil exploration contribute to the release of obnoxious gases into the atmosphere. Moreover, the proliferation of small-scale mining activities in some countries in the region leads to indiscriminate disposal of waste chemicals which pollute the air, land, and water bodies. Concerning gas and oil exploration, the burning of natural gas to dispose of gas generates nitrogen dioxide, carbon dioxide, and photochemical oxidants. The power generation and flaring of hydrocarbons during the well testing and clean-up operations also pollute the environment. In general, FDI in the industry requires more energy to fuel economic activity which might have had a negative spillover effect on economic growth decreasing energy efficiency and reducing clean energy thereby generating pollution.

The result also reveals a non-linear relationship between FDI per capita and CO_2 emissions. The coefficient of the quadratic term of industry FDI per capita is negative and significant. This implies an inverted U-shaped relationship between industry FDI per capita and CO_2 emissions. Thus, in the long run, FDI per capita in the industrial sector supports the EKC hypothesis. Thus, the conventional explanation of the EKC hypothesis applies to the industrial sector in the sampled SSA countries. This could be attributed to the fact that initially, citizens might trade off a cleaner environment for jobs and incomes but beyond a certain threshold, they then begin to demand a cleaner environment. Furthermore, the turning point of the inverted EKC in the industrial sector could be attributed to the response of SSA countries to the Kyoto protocol signed in 1997 and the Copenhagen protocol adopted in 2009 which entreat countries to reduce the levels of GHG concentration.

Initially, foreign firms may take advantage of lax environmental regulations in developing countries to engage in polluting activities. However, pollution tends to fall when countries begin to distance themselves from the pollution associated with their consumption. Distancing could be achieved by either moving people away from pollution or moving pollution away from people. Thus, distancing could be a potential cause of EKC results. In contrast, a U-shape hypothesis holds for the agricultural sector and a linear relationship exists for FDI flows to the services sector showing that the EKC hypothesis may depend on sectoral flows of FDI. It could be argued that a greater percentage of FDI goes into the extraction industries and generate more pollution in those industries compared to the agriculture and services sector.

In column (3), the results also demonstrate that FDI per capita in the industrial sector pollutes the environment. This is plausible in that inflows of FDI in the industry require more energy to fuel economic activity increasing CO_2 emissions. Thus, FDI might have had a negative spillover effect on economic growth decreasing energy efficiency and reducing clean energy use causing pollution. However, the study reveals that domestic investment improves the environment. Some studies (Talukdar and Meisner, 2001; Narayan and Narayan, 2010) reveal that private sector involvement in economic activity, a well-developed financial sector, strong institutions, and effective policies reduce pollution in developing countries.

In column (4), investment in the services sector reduces CO_2 emission in the sector and the coefficient on the quadratic term is negative. This is plausible in that the services sector is ICT-driven based on efficient technology. Once an economy attains matured level of economic development, it shifts from the industrial to the service sector which is less energy intensive and emits low CO_2 emissions.

In general, results are mixed regarding the effect of sector-level FDI per capita on the environment. Whereas the effect of FDI per capita is positive for the industrial sector, it is negative for both the agricultural sector and the services sector. In SSA, business activities are either small or micro with low technical know-how and few or no linkages with larger more dynamic enterprises.

Similar to the results at the aggregate level, the interactive term between FDI in the service sector and domestic investment in the service sector pollutes the environment for the same reason outlined above. In the same vein, import in the service sector hurts the environment. Financial market development also fuels pollution in the service sector.

Finally, in column (2), the effect of urbanization on agricultural CO_2 emission is positive. Particularly, a 1 % increase in urbanization raises CO_2 emissions in the sector by 0.031. Similarly, in column (3), a 1 %

increase in urbanization raises industrial CO_2 emission by 0.075. These result s are plausible in that urbanization and population explosion in the region may require an increased need for land for settlement and agricultural production to meet food demand. Since the forest can capture and store CO_2, clearing land either for settlement or agricultural purposes may release tons of CO_2 into the atmosphere. In addition, the demand for building materials such as cement to meet the demand for houses is a major source of CO_2 emission. Furthermore, urbanization could lead to both human and vehicular traffic with an increase in energy used for economic activities leading to pollution.

4.2. Robustness checks

To validate our findings, we check for robustness using the panel Fully Modified Ordinary Least Square (FMOLS) estimator. FMOLS technique delivers reliable estimates in small samples and is immune to large-size distortions when endogeneity and heterogeneous dynamics are present. The results of the FMOLS regression are presented in Table 5 below.

The panel FMOLS regression result in Table 5 above also suggests that the cumulative nature of CO_2 in the area has a significant, long-lasting effect. This is consistent with the system GMM results obtained in Table 4. The FDI per capita coefficient is negative and statistically significant indicating that FDI per capita lowers overall CO_2 emissions in the 36 SSA countries. The result of the sectoral analysis in Table 5 also reveals that industry FDI increases CO_2 emissions, while agricultural FDI and service FDI decrease CO_2 emissions consistent with the results obtained in Table 4.

5. Conclusion and policy recommendations

The literature on the impact of FDI on the environment has generated divergent results due to different approaches and limitations associated with methodologies used in previous studies. We address the deficiencies in existing studies by investigating the heterogeneous effect of sector-level FDI on carbon dioxide emissions using system GMM estimation technique on a data of 36 sampled countries from 1990 to 2016 in SSA. The present study tests the halo effect hypothesis which argues that FDI improves the environmental quality of the host country and the pollution haven hypothesis which postulates that the growth propelled by FDI comes at the cost of the environment. We find that the results vary depending on the sector. The study revealed that FDI into industry harms the environment validating the pollution haven hypothesis. It is also likely that the presence of foreign firms in the industrial sector is not the only cause of pollution in that sector but lax environmental conditions in SSA could limit the technological innovation that allows them to exploit the spillover effect of FDI.

The study further revealed that FDI flowing to agricultural and services sectors improves the environment which parallels the total FDI result. This implies that foreign firms engage sophisticated technology and management styles in these sectors which promote the quality of the environment. It could be argued that the environmentally friendly effect of FDI observed in agricultural and services sectors outweighs the pollution effect in the industrial sector resulting in an overall improvement of aggregate FDI on the environment.

We also investigate the Environmental Kuznets Curve effect (an inverse U-shaped relation between sector-specific FDI and carbon dioxide emission). In general, a U-shape hypothesis holds for the agricultural sector and an inverted U-shape for the industrial sector. However, a linear relationship exists between FDI flows to the services sector and pollution. It is evident that studies relying on aggregate data to examine the link between FDI and environmental pollution miss the delicate features of the data due to the complex interaction of sectoral FDI with the environment. Thus, studies that depend solely on aggregate data may result in wrong conclusions and policy prescriptions.

Based on the findings from the study, the following recommendations were made. In the industrial sector, an inverted U-shaped relationship exists between FDI and environmental pollution. This suggests that the industrial sector should employ environmentally friendly and energy-efficient methods of production to increase domestic production while reducing pollution at the same time. Environmentally friendly and energy-efficient techniques of production could help conserve natural resources, especially energy resources to meet the rising energy demand for sustainable economic development. In addition, green renewable energy from wind, geothermal, heat, and sunlight can be introduced to reduce pollution from natural energy consumption sources such as oil, natural gas, and coal.

Furthermore, there is a need to strengthen environmental laws concerning investment in the industrial sector and examine the environmental impact of foreign investment before granting them permit to operate. Again the development of human capital and technical know-how in local industries is key to ensuring that SSA reaps the full benefit of FDI.

In the agricultural and services sectors, the results validate the halo effect hypothesis. The implication is that these sectors stand to gain from the clean technology and managerial expertise that FDI brings to these sectors. Thus, policymakers should offer incentives to attract investments in the agricultural and services sector to exploit the full benefits of clean technology in these sectors.

The limitation of the study is that it did not control for governance indicators (institutions). For further study, we suggest that institutions should be controlled for in the sector-specific models to ascertain the effect of sectoral FDI on the environment in SSA.

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.

Appendix 1. 36 sampled countries in SSA

Benin	Madagascar
Botswana	Malawi
Burkina Faso	Mauritania
Burundi	Mauritius
Cameroon	Mozambique
Central African Republic	Namibia
Comoros	Nigeria
Congo, Dem. Rep.	Rwanda
Congo, Rep.	Senegal
Cote d'Ivoire	.Seychelles
Eritrea	Sierra Leone

(continued on next column)

(*continued*)

Benin	Madagascar
Gabon	South Africa
Gambia, The	Sudan
Ghana	Swaziland
Guinea	Tanzania
Guinea-Bissau	Togo
Kenya	Uganda
Liberia	Zimbabwe

Appendix 2. Pairwise Correlation Test

	$\ln CO_2$	lnFDI	lnGDP	lnDOI	lnIMP	lnEXP	lnFMD	lnURB
$\ln CO_2$	1.000							
lnFDI	0.029	1.000						
lnGDP	0.071*	0.055	1.000					
lnDI	−0.026	−0.275*	0.029	1.000				
lnIMP	0.117*	0.138*	0.073*	−0.027	1.000			
lnEXP	0.074*	0.079*	−0.005	−0.011	0.122*	1.000		
lnFMD	0.106*	−0.008	0.068*	−0.037	0.020	0.001	1.000	
lnURB	0.102*	0.013	−0.046	0.039	0.031	0.084*	−0.018	1.000

*Denotes statistical significance of collinearity.

Appendix 3. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
$\ln CO_2$	892	34.87	1.31	23.45	36.83
lnFDI	887	19.24	2.99	0.80	25.53
lnGDP	965	35.52	1.14	29.17	36.84
lnDI	865	0.20	2.01	30.07	13.29
lnIMP	943	35.58	0.91	25.73	36.83
lnEXP	943	35.44	0.97	30.28	36.81
lnFMD	924	35.25	0.94	30.31	36.84
lnURB	967	10.44	3.24	3.22	36.83

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