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Article

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Carbon Emissions and Growth: The Role of Trade and Urbanization in Sub-Saharan Africa

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ABSTRACT

In this study, we employed a system generalised method of moments (GMM) to investigate the effect of trade, urbanization, and income on the environmental quality in a panel of 48 Sub-Saharan African countries, covering the period 1990-2018. Our findings demonstrated that urbanization does not have significant explanatory power over carbon emissions, whereas, trade positively and significantly drives emissions. Our findings further exhibit an inverted U-shape relationship between income and carbon dioxide emissions. This substantiates the existence of an Environmental Kuznets Curve (EKC) in Sub-Saharan Africa. It is therefore concluded that policymakers can focus on growth-promoting policies and should not adopt stringent conservative policies, which may hurt growth and delay the process of reaching a turning point in the Kuznets curve.

Keywords: Trade; Emissions; Growth; Urbanization; Environmental Kuznets Curve
JEL Classifications: C13; C23; Q43; Q56

1. INTRODUCTION

Climate change is fast becoming one of the greatest socio-pathological challenges of our time. There has been a substantial increase in CO_2 levels in recent years (from 2020 to 2021), surpassing the average annual growth rate recorded over the past decade. Correspondingly, the largest annual increase in methane was recorded around the same period (Songwe, 2024). Perhaps predictably, some sources of data have suggested that the year 2022 might be the fifth if not the sixth warmest year ever recorded. Closer to home, in the last six decades, Africa has endured a warming trend that, for the most part, has been faster than the global average. Expectedly, climate change trends in Africa also vary from one region to another. The largest increase in GHG emissions between 1990 and 2018 was observed in Ghana (8.12%), Burundi (4.14%), and Gambia (1.82%). Oppositely, other African nations, including Equatorial Guinea (−5.6%), and Seychelles (−3.74%), recorded considerable declines in GHG emissions (Espoir and Sunge, 2021). Such drastic changes in climate carry a lot of risk for various regions in Africa that are already susceptible to many other socio-economic pathologies. Climate change is likely to push many poor regions such as the Sub-Saharan region to the brink of poverty, inequality and unemployment if decisive policy actions to mitigate it are delayed (Jafino et al., 2020). In his recent work Songwe, (2024:36) writes: "Droughts and floods are worsening agriculture productivity and increasing Africa's dependence on food imports, worsening the current account balance, and displacing productive investments." Realizing the potentially devastating impact of climate change on climate-sensitive sectors and economic development in general, policymakers in Africa have made some efforts aimed at dealing with and coping with climate change. One of the strategies that has been adopted as a policy response to coping and moderating climate change, and assisting regional collaboration and reinforcement of international partnerships is the African Union Climate Change and Resilient Development Strategy and Action Plan. The primary goal of this strategy is "To provide a continental framework for collective action and enhanced cooperation in addressing climate change issues that improves livelihoods and well-being, promotes adaptation capacity, and achieves low-emission, sustainable economic growth." The African Union Climate Change and Resilient Development Strategy and Action Plan is not a home-grown solution to climate change but is premised on the continent's obligation to fulfil an effective multilateral approach as outlined by the United Nations Framework Convention on Climate Change as well as the ensuing Paris Agreement.

Despite these promising efforts, climate change has been increasing in Africa due to various factors, including urbanization, trade openness and economic growth. The substantial increase in the number of people moving from rural areas to metropolitan areas in Sub-Saharan African nations has led to a rise in energy consumption and construction activities, leading to higher emissions of greenhouse gases (GHGs). A study conducted in South Africa found evidence to suggest that a 1% rise in urbanization is accompanied by an average increase of 0.4595% in environmental pollutants (Shahbaz et al., 2013). By the same token, economic activities (economic growth) in Sub-Saharan African nations every so often depend on sectors that are mostly driven by fossil fuels which in turn worsen GHG emissions. Economic growth itself also contributes to a substantial increase in consumption and production, thereby escalating the environmental impact.

There is a growing strand of literature investigating the effect that urbanization, trade and/or economic growth might have on CO_2 emissions (Al-Mulali et al., 2015; Ertugrul et al., 2016; Khamjalas, 2024; Adams and Klobodu, 2017; Sharma, 2011; Zaidi et al., 2018; Fakih and Marrouch, 2019). Nevertheless, the existing body of literature indicates that a consensus regarding the relationship between these variables has yet to be grasped. Thus, this study aims to assess the relationship between economic growth, trade, urbanization and CO_2 emissions in Sub-Saharan Africa. Uncovering the interplay between emissions, trade, urbanization, and growth is crucial for developing optimal carbon management policies. There is a plethora of reasons why Africa is an interesting case to study. First, to promote growth and development through trade, the region adopted the African free continental trade area (AfCTA). In theory, this will enable countries in the region to trade more with each other and will result in increased production. This, in turn, will stimulate the consumption of energy and thus, emissions. On the other hand, trade may exert a negative effect on carbon emissions. There is evidence suggesting that trade induces technology spillovers (Keller, 2010; Wang, 2007). In this vein, Zhu and Jeon (2007) demonstrate that bilateral trade is a primary conduit for international research and development (R&D) externalities. Therefore, increased trade between countries could result in the sharing of knowledge and energy-efficient and cleaner technologies, consequently, reducing carbon emissions. Hence, an in-depth examination is essential to understanding the interplay between carbon emissions and trade. Consequently, the environmental implications for the implementation of the AfCTA.

Globally, urbanization is expected to soar from 56% in 2021 to 68% by 2050. This represents an increase of approximately 2.2 billion urban residents, dwelling mostly in Africa and Asia. On the other hand, the urbanization rate is expected to stabilize and decline in developed nations. According to the Organization for Economic CD (OECD), Africa has the fastest urban growth. It is further argued that the region's population will double by 2050, and more importantly, nearly two-thirds of this growth will be absorbed in urban areas. It is therefore surprising that, while studies exploring the link between urbanization and emissions exponentially increased, the focus has been more on Asian economies, and other regions, thus neglecting Africa as a ground for research. Previous studies are less useful in understanding the relationship between urbanization and emissions because they often document conflicting evidence. Moreover, previous studies reveal that the role of urbanization may vary across regions, thereby, warranting a study concentrating on the African region. In theory, urbanization is expected to increase energy consumption, amongst other things, which, in turn, results in elevated environmental degradation. On the other hand, urbanization may results result in a decline in carbon emissions. Understanding the link between emissions and growth is imperative for planning for the expected surge in urbanization in Africa. It will assist countries to better prepare and design policies that will ensure that the process of urbanization does not adversely impact the environment.

Our findings substantiate the environmental Kuznets curve (EKC), suggesting at lower levels of income, emissions increase with growth but decrease with income at higher levels of income. It is further shown that trade stimulates the degradation of the environment, while urbanisation does not significantly affect the quality of the environment. The remaining sections of the study are structured as follows: Section 2 offers a brief literature review. Section 3 discusses the data and methodology used in the study. Section 4 discusses the results in detail whereas Section 5 concludes the study with some policy implications.

2. BACKGROUND

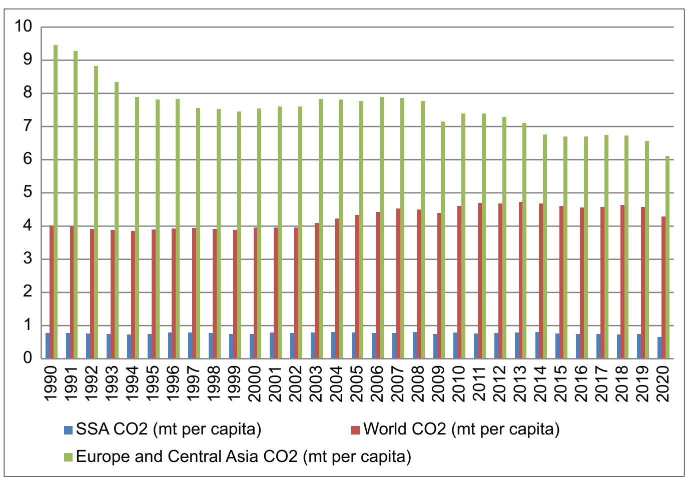
On average, our data reveals that, for the period under consideration, the average CO_2 were recorded at 0.83 metric tons per capita, which is far less relative to other regions. For instance, emissions were 5 times lower relative to the global average for the sample period and 9 times lower compared the Europe and Central Asia (Figure 1).

In theory, low-income countries and developing nations are expected to have higher levels of carbon emissions. This is because these economies often rely on dirty technologies, whereas developed areas are more concerned about the quality of the environment, and thus have massive investments in cleaner technologies. However, the reality seems to be at odds with theoretical predictions. The data demonstrates that high-income countries, such as the United States (US), Germany, and China, among others, are the largest polluters in the world, whereas, developing and low-income countries such as Sub-Saharan Africa are the least polluters in the world. This revelation, thus, casts doubts on the applicability of the so-called environmental Kuznets hypothesis (EKC). The average income per capita in Sub-Saharan Africa (1990-2020) was recorded at US$1430, which is far below the world average (US$8644), the OECD average of US$31764, US$31764 in the Euro Zone, and US$6743 in East Asia for the same period (Figure 2).

This theoretical inconsistency warrants further investigation of the association between income or economic progress and environmental quality, especially in regions such as Africa, where economic progress appears to be relatively stagnant.

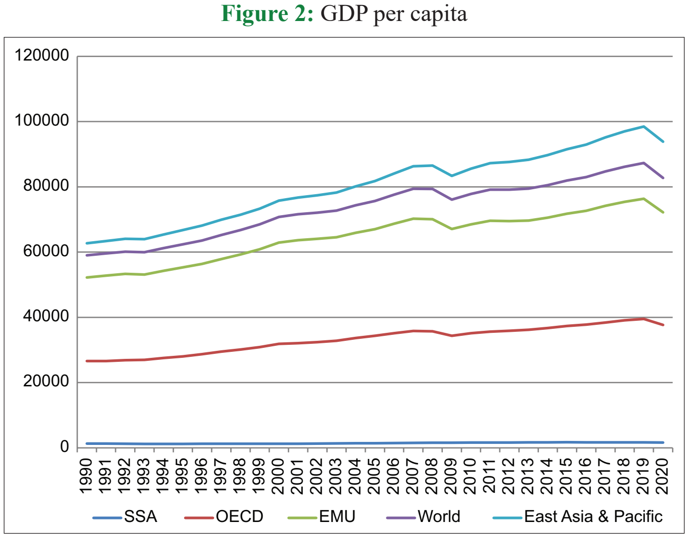
Several attempts have been made to boost intra-regional trade in Africa, such the establishment of regional economic communities. While trade in Africa has grown (to nearly 60% of GDP), intra-regional trade remains disappointingly low (Beck and Nzimande, 2023). A new initiative, that is, the African Continental Free Trade Area, has been implemented in an effort to boost intra-continental trade. Thus, as alluded previously, trade among the countries in the region is expect to soar, and this could put an upward pressure on emissions as documented, that is if the sustainability of environment is not fully considered in the implementation of this initiative. All these combined with the fact that urbanization in Africa is growing faster than in other regions, warrants efforts to holistically analyse how environmental quality might be affected by these developments in Africa.

Figure 1: Carbon emissions (metric tons per capita)



Source: Authors' computation

Figure 2: GDP per capita



Source: Authors' computation

3. LITERATURE

The literature extensively examines the relationship between economic growth and greenhouse gas emissions, with a special emphasis on verifying the validity of the EKC hypothesis. The findings of the studies either confirm the EKC hypothesis or the non-existence of the EKC hypothesis (Kais and Sami, 2016, Chen et al., 2016). Grossman and Krueger (1991) were amongst the first studies to realise three different pathways: scale, composition and technique effects in which economic growth influences environmental quality.

The scale effect states that at the start of an economic growth path, more resources and inputs are used to produce more commodities. Therefore, as energy resources and production expand, so do pollution emissions and greenhouse gas emissions. According to the composition effect, structural transformation is brought about by economic growth; when a country's production increases, the economy shifts its structure to include less environmentally harmful industries. The final channel of the growth impact on GHG emissions is the technique effect channel. When high-income economies invest more in R&D, new technological processes emerge, outdated and dirty technologies are replaced with modern, clean ones, dematerialization and transmaterialization effects take place, and environmental quality deepens.

Whether the environmental Kuznets curve is only limited to developed or high-income countries remains controversial in the literature. For instance, Bibi and Jamil (2021) study the association between economic growth and environmental degradation across different regions: Latin America and the Caribbean, East Asia and the Pacific, South Asia, Middle East and North Africa, and Sub-Saharan Africa. They find evidence substantiating the EKC hypothesis in all regions except for Sub-Saharan Africa (SSA). They conclude that EKC does not exist in regions like SSA where most countries are low-income countries and income levels are below the turning point.

Wang et al. (2024) examine the relationship between economic growth, trade protection and environmental degradation. These scholars find evidence supporting the environmental Kuznets curve hypothesis across all income strata, contrasting Bibi and Jamil (2021). Wang et al. (2024) further find that protectionism reduces emissions in high-income countries, whereas, in other income groups, it has a stimulating effect on environmental degradation. Focusing on Brazil, China, India, and Indonesia, Alam et al. (2016) found that for all countries considered except for India, the EKC hypothesis held. These scholars, therefore, conclude that the increase in emissions is only transitory and countries should not adopt conservative policies as they may hinder growth, which is required to push the country beyond the turning point. In the case of India, they find that emissions will not decrease as income increases, thereby government should promote sustainable or environmentally friendly policies.

Caviglia-Harris et al. (2009) use ecological footprint, which they consider a comprehensive measure of environmental degradation, to investigate the EKC hypothesis. They find that there is no evidence of EKC, but find limited support of it for some components of ecological footprint. Murshed et al. (2022) employ carbon and ecological footprints to test the validity of EKC in five South Asian economies: Bangladesh, India, Pakistan, Sri Lanka, and Nepal. They document evidence of the EKC hypothesis in all countries except for Pakistan. They argue that growth is both a short-run cause of environmental degradation and a solution in the long-run.

Most of the studies focused on multi-country studies while a few focused on single-country studies. Naz et al. (2019) focused on Pakistan using the Robust least square estimator and realised that economic growth increases carbon emissions. In a similar study focusing on Nigeria, Ali et al. (2019) found that economic development is positively associated with carbon emissions. The multi-country studies were carried out by Abban et al. (2020) and Adedoyin et al. (2020) for BRI and BRICS countries, respectively. Employing the augmented mean group method, Abban et al. (2020) realised a bidirectional causality flowing between economic growth and carbon emissions while Adedoyin et al. (2020) found that economic growth induces carbon emissions using Panel-Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL). Other multi-country studies that established that economic growth contributes to carbon emissions include Saint Akadiri et al. (2020) in the OECD countries and Muhammad (2019) in MENA countries.

The existing literature offers little guidance concerning the effect of urbanization on carbon emissions. There exists a strand of the literature suggesting that urbanization has a stimulating effect on carbon emissions (Pata, 2018, Verbič et al., 2021). Another strand of the literature, however, suggests that urbanization negatively affects emissions. For example, Martínez-Zarzoso and Maruotti (2011) found that urbanization reduces emissions.

Urbanisation is primarily the process through which communities and towns are created, growing larger as more people start residing and working in urban areas (Gries and Grundmann 2018). The impacts of urbanization on the environment are numerous. One of the main effects urban POP has on the environment is the occurrence of eutrophication on water bodies. Large cities experience rain when it rains, which filters air pollutants like CO_2 emissions and other greenhouse gases into the ground. These substances flow straight into rivers, streams, and seas, degrading marine habitats by lowering water quality (Zhang, 2020).

Numerous studies have been conducted on the relationship between URB and CO_2 emissions. Nonetheless, the findings are not all the same. Some studies realised strong evidence of the Kuznets curve in the relationship between urbanisation and carbon emissions (Abdulqadir 2023 and Chen et al. 2019). On the contrary, Xie and Liu (2019) revealed that urbanisation does not display an inverted U-shaped curve connection with CO_2 emissions. Some studies established that there is a positive nexus between urbanisation and carbon emission. These include studies by Salahuddin et al. (2019) for SSA countries, Dong et al. (2019) for 14 developed countries and Adusah-Poku (2016) for SSA countries. On the contrary, Ly and Xu (2019) established a negative connection between urbanisation and carbon emissions in 55 middle-income countries.

As Africa seeks to intensify intra-regional trade it is important to understand how trade influences emissions. It is generally argued that trade, especially in developing and low-income countries, such as Africa, trade stimulates environmental degradation. On the other hand, trade results in technology spillovers, which, in turn, may have adverse effects on emissions. The interplay between trade and emissions is less clear-cut in the literature, with some studies finding no significant relationship, and others finding positive relationship. For example, Ozatac et al. (2017) find that trade positively influences carbon emissions, whereas, Koc and Bulus (2020) find that trade openness is associated with a reduction in carbon emissions per capita. Thus, supporting that trade does not only involve the movement of final goods but also entails technological spillovers. Dogan and Turkekul (2016) using Granger causality find that there is no causal relationship between greenhouse gas emissions and trade openness. Cetin et al. (2018) undertook a study of Turkey for the period between 1960 and 2013. The results from the Vector Error Correction Model (VECM) revealed that trade openness Granger causes carbon emissions. Mutascu (2018) found that trade has a positive effect on carbon emissions in France.

Ali et al. (2020) conducted a study in the OIC countries to assess the relationship between trade openness and carbon emissions covering the period between 1991 and 2016. Using a Dynamic Common Correlated Effects model (DCCE), these scholars reported that trade significantly affects environmental quality. Focusing on 55 middle-income countries, Lv and Xu (2019) other studies by documenting that trade harms the environment in the long run. Sun et al. (2019) conducted a study for SSA countries covering the period from 1990 to 2014 and realised that trade openness reduces carbon emissions. Similar results of trade adversely affecting carbon emission were established by Zafar et al. (2019) for emerging countries.

Overall, the literature suggests that the debate on the environmental effects of GDP, trade, and urbanization is still far from being settled (Table 1 for a summary). Evidence from previous studies is conflicting and inconclusive, consequently warranting more studies to ascertain the influence of these variables.

4. DATA AND METHODOLOGY

4.1. Data Sources

To explore the link between growth, trade, urbanization, and environmental quality, we use panel data covering the period 1990-2018. Our sample consists of 48 Sub-Saharan African (SSA) countries, and five variables are considered. All the data was collected from the World Development Indicators (WDI) of the World Bank. The variables considered in the analysis are:

4.2. Model Specification

To assess the link between trade, income, urbanization, and environmental quality, we employ the following equations. Drawing

Authors	Countries	Period	Methods	Findings
The relationship between economic growth and carbon emissions				
Abban et al. (2020)	BRI	1995-2015	AMG, DH	Economic growth ⇆ CO_2 emissions
Adedoyin et al. (2020)	BRICS countries	1990-2014	PMG-ARDL	Economic growth induces emissions of CO_2
Baajike et al. (2022)	37 SSA countries	1995-2017	PMG-ARDL	Urbanisation and CO_2 not significant nexus GDP and CO_2 have a negative nexus URB ⇆ CO_2
Akadiri et al. (2020)	OECD countries	1995-2014	Granger causality	Economic growth contributes to environment pollutions
Alaganthiran and Anaba (2022)	SSA	2000-2020	pooled ordinary least square (OLS), fixed effects model (FEM), random effects model (REM) and robust fixed model,	GDP increases CO_2 International tourists' arrival decreases air quality
Ali et al. (2016)	Nigeria	1971-2011	ARDL	GDP and EC have positive impact on CO_2 Trade has negative impact on CO_2
Gorus and Aydin (2019)	MENA countries	1975-2014	Granger causality	CO_2 emissions⇎EC
Hanif (2017)	SSA	1995-2015	GMM	URB stimulates CO_2 In inverted U-shaped nexus between GDP and CO_2
Iheonu et al. (2020)	SSA		Quantile regression	GDP increases CO_2 International trade improves environmental sustainability, URB increases CO_2 emissions. ⇆ GDP, TR, URB & CO_2
Naz et al. (2019)	Pakistan	1975-2016	RLSR	Pollution hypothesis havent been supported
Nkengfack et al. (2019)	SSA	1996-2014	combine static and dynamic panel estimation technique to quantile regression.	GDP increase CO_2 Exports increases CO_2 imports decreases CO_2
Muhammad (2019)	MENA countries	2001-2017	DSUR, GMM	Increase economic growth increases CO_2 emissions
Odugbesan and Murad (2019)	SSA	1993-2014	Fixed/Random effect model	CO_2 and URB have+ve effect on GDP
Ssali et al. (2018)	SSA	1990-2014	VECM, FMOLS	EC increases CO_2 and EC increases GDP
The relationship between trade and carbon emissions				
Ali et al. (2020)	OIC countries	1991-2016	DCCE	Trade has a positive and significant impact on environmental quality.
Cetin et al. (2018)	Turkey	1960-2013	VECM	TRD⇒CO_2 emissions, EKC hypothesis is valid
Lv and Xu (2019)	55 middle-income countries	1992-2012	PMG	Trade harmfully affects the environment in the long run
Mutascu (2018)	France	1960-2013	Time series	CO_2 emissions positively affected by the trade
Sun et al. (2020)	SSA	1990-2014	EKC	Trade openness have a negative impact on CO_2
Zafar et al. (2019)	Emerging economies	1990-2015	VECM	Trade adversely affects the CO_2 emissions
The relationship between urbanisation and carbon emissions				
Abdulqadir (2023)	SSA	1990-2019	dynamic panel quantile regression	Strong evidence of Kuznets curve in connection between urbanization, GDP, RE, trade and CO_2 emissions
Adusah-Poku (2016)	SSA	1990-2010	PMG	Urbanisation and population increase CO_2 both in the short and long run
Ali et al. (2019)	Pakistan	1972-2014	ARDL	URB⇒CO_2 emissions
Chen et al. (2019)	Chinese prefecture level cities	2005-2013	STIRPAT Model	Inverted U-shape curve between URB and CO_2 emissions
Dong et al. (2019)	14 developed economies	1970-2013	Threshold Regression	URB contributes to the growth of CO_2 emissions
Lv and Xu (2019)	55 middle-income countries	1992-2012	PMG	Urbanization has a negative and significant impact on CO_2 emissions
Salahuddin et al. (2019)	Sub-Saharan Africa	1980-2017	ARDL	Urbanization induces CO_2 emissions
Xie and Liu (2019)	30 provinces in China	1997-2016	STIRPAT Model	URB does not display an inverse U-shaped curve correlation with CO_2 emissions

inspiration from the studies conducted by Grossman and Krueger (1995), Shafik (1994), and Bibi and Jamil (2021), we specify the three straightforward models—the linear (1), quadratic (2), and cubic (3). This approach allows us to examine the pattern of the association between environmental quality and income, along with other variables of significance. The models are outlined as follows:

$$CO_2=\beta_0+\alpha_1 \ln GDPpc_{it}+\alpha_3 TR_{it}+\alpha_4\ UR_{it}++\varepsilon_{it} \quad (1)$$

Table 1: Fixed effects estimates

Variables	(1) Model 1	(2) Model 2	(3) Model 3	(4) Model 4	(5) Model 5	(6) Model 6
GDP	0.413***	0.669***	0.820	−0.0794	−0.419	0.515**
	(0.0213)	(0.164)	(1.133)	(1.346)	(1.329)	(0.203)
GDP-squared		−0.0185	−0.0401	0.0970	0.117	−0.0163
		(0.0118)	(0.161)	(0.191)	(0.188)	(0.0146)
GDP-cubed			0.00100	−0.00584	−0.00624	
			(0.00745)	(0.00889)	(0.00877)	
Trade				0.175***	0.142***	0.137***
				(0.0426)	(0.0424)	(0.0418)
Urbanization					0.694***	0.694***
					(0.122)	(0.122)
Constant	−4.007***	−4.866***	−5.210**	−3.985	−4.811	−6.920***
	(0.144)	(0.564)	(2.615)	(3.083)	(3.045)	(0.695)
Observations	1,314	1,314	1,314	1,176	1,176	1,176
R-squared	0.229	0.230	0.230	0.202	0.225	0.224
Number of countries	48	48	48	45	45	45

Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1

$$CO_2 = \beta_0 + \alpha_1 lnGDPpc_{it} + \alpha_2 lnGDPpc_{it}^2 + \alpha_3 TR_{it} + \alpha_4 UR_{it} + + \varepsilon_{it} \quad (2)$$

$$CO_2 = \beta_0 + \alpha_1 lnGDPpc_{it} + \alpha_2 lnGDPpc_{it}^2 + \alpha_2 lnGDPpc_{it}^3 + \alpha_3 TR_{it} + \alpha_4 UR_{it} + + \varepsilon_{it} \quad (3)$$

Where CO_2 represents carbon emissions, Y_{it} is economic growth, TR_{it} denotes international trade, URB_{it} represents urbanization, and ε_{it} represents traditional error terms.

The main issue with Equations 1-3 concerns the appropriate procedure for estimating it. If there are unobserved factors influencing carbon emissions but are not captured in the model, it may induce a temporal correlation in the disturbances. To address this, our baseline regression estimates equation (1-3) using Generalised Least Squares (GLS). It is assumed that the error term has two components:

$$\varepsilon_{it} = \eta_i + u_{it} \quad (4)$$

Where η_i represents country-specific effect and are idiosyncratic error terms. We assume that $cov(\eta_i, \eta_j) = 0$ and $cov(u_{it}, u_{jt}) = 0 \ \forall \ i \neq j$ and $t \neq s$. We, therefore, employ the random and fixed effect models to estimate equations 1-3.

Most literature exploring the link between emissions and economic development generally relies on fixed and random effect models (Bibi and Jamil, 2021). Thus, these studies often do not consider autoregressive dynamics, and more importantly, do not allow the covariates to be correlated. Bond (2002) posits that this is an unnatural restriction, especially in economic modelling. In this study, we seek to relax the assumptions of strict exogeneity because the variables considered in this study and existing studies could be jointly determined. For example, there is no reason to believe there is no feedback between trade and output.

In addition, we consider autoregressive dynamics. Wawro (2002) argues that the inclusion of autoregressive dynamics is crucial because it accounts for partial adjustment behaviour over time. For instance, countries might want to adjust their behaviour over time to achieve a certain level of emissions. Further emphasising the significance of autoregressive dynamics, Bond (2002) argues that even if the coefficient of the AR term is not of interest, its inclusion can help to recover consistent estimates for the other parameters in the model. In the same vein, Greene (2003) advances that adding dynamics to a model changes the interpretation of the equation. He argues that in the absence of the lagged dependent variable, the covariates represent the full information that yields the observed outcome $CO_{2,it}$ However, when the lagged dependent variable $CO_{2,it-1}$ is added, we have in the equation the entire history of the right-hand-side variables, so that any measured influence is conditional on this history; in this case, any impact of the right-hand-side variables represents the effect of new information. As a result, there is always often a case for dynamic estimation when analysing panel data. Against this and in addition to our baseline methods (fixed and random effects), we estimate a dynamic panel model using the generalised method of moments (GMM) of Blundell and Bond (1998) and Arellano and Bover (1995). The following equations are considered:

$$CO_2 = \beta_1 CO_{2,t-1} + \alpha_1 lnGDPpc_{it} + \alpha_3 TR_{it} + \alpha_4 UR_{it} + + \varepsilon_{it} \quad (5)$$

$$CO_2 = \beta_1 CO_{2,t-1} + \alpha_1 lnGDPpc_{it} + \alpha_2 lnGDPpc_{it}^2 + \alpha_3 TR_{it} + \alpha_4 UR_{it} + \varepsilon_{it} \quad (6)$$

$$CO_2 = \beta_1 CO_{2,t-1} + \alpha_1 lnYpc_{it} + \alpha_2 lnYpc_{it}^2 + \alpha_2 lnYpc_{it}^3 + \alpha_3 TR_{it} + \alpha_4 UR_{it} + \varepsilon_{it} \quad (7)$$

5. EMPIRICAL FINDINGS

In Tables 1 and 2, we present estimates from fixed- and random-effect models, respectively. Our findings align with many other existing studies, suggesting that national income is a significant driver of environmental quality (Tucker, 1995; Olubusoye and Musa, 2020). It is demonstrated that, except for a few cases, GDP positively and significantly influences carbon emissions.

Table 2: Random effects estimates

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GDP	0.469***	0.611***	0.0570	−0.618	−1.038	0.203
	(0.0215)	(0.168)	(1.169)	(1.377)	(1.354)	(0.201)
GDP squared		−0.0104	0.0688	0.161	0.189	0.0112
		(0.0121)	(0.166)	(0.195)	(0.192)	(0.0145)
GDP cubed			−0.00367	−0.00763	−0.00831	
			(0.00769)	(0.00909)	(0.00893)	
Trade				0.213***	0.171***	0.165***
				(0.0431)	(0.0428)	(0.0422)
Urbanization					0.784***	0.785***
					(0.110)	(0.109)
Constant	−4.410***	−4.886***	−3.626	−2.931	−3.747	−6.559***
	(0.166)	(0.586)	(2.700)	(3.161)	(3.109)	(0.703)
Observations	1,314	1,314	1,314	1,176	1,176	1,176
Number of countries	48	48	48	45	45	45

Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1

We argue that underdeveloped and low-income countries are bound to utilise readily available and inexpensive non-renewable energies, regardless of the consequences it has on the quality of the environment (Hanif, 2018). This is primarily because a larger weight is placed on the developmental agenda (e.g., eradication of poverty) and less on the degradation of the environment.

Across all specifications in Tables 1 and 2 (1-6), our results suggest that both the GDP-squared and cubic terms, do not have any significant explanatory power, indicating a monotonically increasing relationship between GDP and carbon emissions. Thus, contrast to Balsalobre-Lorente et al. (2022), we do not find evidence of a N-shape association between income and environmental degradation. Our findings align with those of Shafik (1994), indicating that the cubic and quadratic terms are not significant estimators of environmental quality. This finding is at odds with several other studies that found that, at lower levels of income, carbon emissions increase with GDP, and decrease with GDP at higher levels of income.

In all our estimations, trade is found to significantly drive carbon emissions. This finding aligns with previous studies, suggesting a positive link between trade and carbon emissions (Grossman and Krueger, 1991, Dogan and Turkekul, 2016, Ertugrul et al., 2016).

Contrary to our expectations, our findings demonstrate that urbanization exerts a positive influence on the quality of the environment. Generally, people migrate to urban areas to search for employment opportunities, better life, and better living conditions and health Dogan and Inglesi-Lotz (2020). Thus, at the initial stages, urbanization tends to be associated with a positive effect on carbon emissions. However, as they transition from inefficient fuel to better alternative energies, the relationship between emissions and income switches to negative. Our findings, though, consistent with the existing literature exhibit that urbanization does not reduce emissions.

Relying on the Hausman test, the random effects model is the most appropriate model for this study. Grossman and Krueger (1991) also applied the same procedure in their estimation. Thus, our preferred model is in line with the existing literature.

Our findings from the dynamic panel estimates are, to a certain degree, at odds with our baseline estimates; that is, fixed and random effects. In particular, the AR parameter is found to be a significant driver of emissions in the present period. This finding is consistent across all three specifications. In line with our previous estimates (Tables 1 and 2), we find the level of income to be a significant determinant of carbon emission; that is, an increase in income is associated with an increase in emissions, thus environmental degradation.

Interestingly, our findings are in support of the EKC hypothesis. The squared term is negative and statistically different from zero (see column 2). These findings are in line with previous studies (Li et al., 2024, Erdogan, 2024). This suggests that at lower levels of income, emissions increase with GDP, but decrease at higher levels of income. This is partly because developing countries prioritise development/or high economic growth over the environment. Due to the rise in economic growth, per capita income increases, which, in turn, leads purchasing of items such as vehicles and other polluting products (Bibi and Jamil, 2021). On the other hand, high-income countries are concerned about the quality of the environment and its health consequences and thus, invest more in better and cleaner technologies.

Similarly, to the estimates reported in Tables 1 and 2, we find trade to exert a positive and statistically significant effect on emissions. It is generally argued that trade allows a country to expand its production possibilities. However, more production results in increased pollution. Thus, trade exerts a sanguine influence on the degradation of the environment. Moreover, the positive relationship between trade and carbon emissions could be explained by the so-called pollution haven hypothesis (Kaika and Zervas, 2013). Higher-income countries, with stringent regulations on pollution, may exploit the fact that regulations are generally loose in low-income and developing countries, and thus shift their pollutant production to developing countries. These findings exhibit the importance of ensuring environmentally friendly trade deals must be encouraged and promoted. Furthermore, and in light of the AfCTA, our findings demonstrated the need to maintain effective and efficient cross-country environmental governance. This, in the context of Africa, will ensure that the objectives of the

Table 3: Dynamic panel estimates- systems GMM

Variables	(1) Linear Model	(2) Quadratic Model	(3) Cubic Model
lagged CO_2	0.973***	0.975***	0.975***
	(0.00732)	(0.00774)	(0.00773)
GDP	0.0291***	0.138***	0.203
	(0.00754)	(0.0312)	(0.264)
GDP-squared		−0.00765***	−0.0168
		(0.00220)	(0.0370)
GDP-cubic			0.000422
			(0.00170)
trade	0.0164*	0.0180**	0.0179**
	(0.00855)	(0.00867)	(0.00882)
urbanization	−0.00417	−0.0111	−0.0114
	(0.0115)	(0.0121)	(0.0119)
Constant	−0.265***	−0.620***	−0.769
	(0.0767)	(0.111)	(0.614)
Observations	1,137	1,137	1,137
Number of countries	45	45	45

Robust standard errors in parentheses. *** P<0.01, ** P<0.05, * P<0.1

current and future trade deals are implemented without harming the environment.

Contrary to our baseline results, Table 3 exhibits that urbanization does not significantly affect emissions. This finding is at d odds with the findings of Hanif (2018). He found that urbanization had a positive and significant impact on carbon emissions. It is noteworthy that there is no consensus in the literature concerning the effect of urbanization on emissions. Other studies argue that the effect of urbanization is sensitive to the proxy used for economic growth (Dogan and Inglesi-Lotz, 2020). We advance that it should not be a surprise that urbanization does not significantly affect emissions. This is because the population migrates to urban areas to access employment and better living conditions (Dogan and Inglesi-Lotz, 2020). These areas may have access to better and cleaner energy. Consequently, urbanization neither has a negative nor positive effect on carbon dioxide emissions.

6. CONCLUSION

Over the years, the consumption of energy has substantially increased, resulting in massive carbon emissions, which are arguably the main driver of the climate change crisis. Against this backdrop, this study investigated the interplay between income, trade, urbanization, and carbon emission in 48 Sub-Saharan African countries over the period 1998-2018. In line with existing studies, we specify three equations: linear, quadratic, and cubic to capture the shape of the relationship. Consistent with existing literature, we estimated fixed and random effect models and interesting results emerged from our analysis.

First, our baseline estimates suggested a monotonically increasing relationship between income and emissions. Both the fixed and random effect models do not find the quadratic and cubic terms to be significant estimators for emissions. However, when considering the possibility that carbon emissions could be influenced by past levels of emissions, we find evidence of the environmental Kuznets curve (EKC) hypothesis, which asserts that carbon emissions increase with income at lower levels of GDP but decrease at higher levels of income. We argue that this is because higher levels of income allow countries to invest in better and cleaner technologies. Moreover, high-income countries can easily shift "polluting" industries to low-income countries and concentrate on the services sector, which is associated with reduced emissions. In contrast with previous studies, we find that whilst urbanization is growing at the fastest pace in Africa, it does not significantly affect carbon emissions. We hypothesise that this could be because people migrate to urban areas in quest for better and improved living conditions. These areas may already have access to cleaner energies, thus urbanization should neither worsen nor reduce environmental degradation. Finding a positive association between trade and environmental quality implies that policymakers should advocate for *green* trade agreements; that is, eco-friendly deals. By extension, in implementing its AfCTA, Africa should continuously search for strategies to ensure that the quality of the environment is not adversely affected. Finally, our findings suggest that countries in Sub-Saharan Africa should concentrate on growth-promoting policies, and not adopt conservative policies, which may hinder growth and consequently delay the process of reaching the turning point in the environmental Kuznets curve.

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