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Transport Energy Consumption and Environmental Quality: Does Urbanization Matter?

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ABSTRACT

Previous studies on environmental quality have emphasised the importance of transportation and urbanization in influencing carbon emission globally. While the theoretical and empirical discussion remain inconclusive and controversial, the question of whether transport energy consumption and urbanization induce emissions of carbon dioxide sub-Saharan Africa (SSA) remain unclear. This study contributes to the ensuing debate on sustainable transportation and urban development, focusing on the link between transport energy consumption, urbanization and carbon emissions in SSA. Using the IV-GMM estimator that accounts for endogeneity and cross-sectional dependence inherent in panel dataset, three key findings emerge from the study. First, we find substantial evidence that CO_2 emission increases with transport energy consumption while it decreases with urbanization. Second, factors such as electricity consumption and population growth rates worsen CO_2 emission, whereas regulation quality and FDI significantly reduce carbon emission in the region. Third, we find that the effect of urbanization and transport energy consumption on CO_2 emission vary quite dramatically across SSA countries. We argue for drastic policies tailored towards reducing carbon emission in SSA.

Keywords: Transport energy; Carbon emissions; Pollution; Environmental degradation; Urbanization

1.0 Introduction

Global warming is known to be caused mainly by greenhouse gases (GHG), of which carbon dioxide is the most abundant (Intergovernmental Panel on Climate Change [IPCC], 2014; Xu & Lin, 2017; Peng et al., 2018). Zhang et al. (2018) have described climate change as the greatest threat facing humanity; therefore, the concern for governments and other stakeholders around the world. Research suggests that carbon constitutes over 60% of the GHG. More importantly, the transport sector contributes over a quarter of global GHG emissions and, consequently, an essential source of anthropogenic greenhouse emissions (WEO, 2017, 2018; Ülengin et al., 2018). The transport sector energy consumption shares, which stood at 18.6% as of 1973, has increased steadily over the period and currently stands at 28.20% of the total energy consumed, which suggests a 1.2% growth annually (World Energy Outlook, 2018).

Research indicates that not much success has been achieved concerning policies implemented to reduce carbon dioxide emissions (IPCC, 2014). More serious is the fact that if nothing is done to curb these emissions at the current rate, the effects of global warming will be more disastrous on the ecosystem and, consequently, human livelihoods. Additionally, Kranbeck (2010) has also noted that delayed action to reduce carbon dioxide emissions now will be very costly and, therefore, prohibitive, especially for developing countries. Accordingly, concrete and immediate targeted measures must be put in place to avoid any calamity (Wang et al., 2018).

In SSA, the data suggest that the transport sector's emissions figure was 22.36% in 1971 but decreased to 19.69% in 1980 and 18.13% in 1990 but continued to increase in 2000 to 19.97, and the highest increase in 2010 to 23.47%. Its highest growth occurred in 2013 when it reached a peak of 23.88% but reduced to 22.85% in 2014 (WDI, 2017). Incidentally, there is a high correlation between carbon emissions, transport energy consumption, and economic growth rate patterns over the period (Africa progress panel [APP], 2015, 2016, 2017). The International Energy Outlook [IEO] (2016) reports that the transport energy consumption is expected to increase to 155 quadrillions Btu by 2040 from 104 quadrillion Btu in 2012. The report further notes that most of the increase is going to come from non-OECD countries, especially in countries with high population and growth rates, as is the case for Africa.

Though many studies have looked generally at the carbon emissions and energy consumption linkage, however, not much attention has been given to the transport energy specifically. This gap motivates our study. In filling this gap, this study contributes to sustainable transport and urban development literature. The study attempts to analyze the role of transport energy consumption and economic growth on carbon emissions for 19 selected African countries while controlling for urbanization and agricultural share in GDP to reduce omitted variable bias in the estimates. Urbanization is considered because many studies do suggest that transportation organizations in urban planning influence carbon emissions (Buehler and Pucher, 2011; Pojani, 2015; Santos, 2017; Wang et al., 2017). We also control for the agricultural share in GDP as most of the economies in the region are agriculturally oriented, which is less harmful to the environment compared to manufacturing (IEO, 2018). This is important because many studies show that the SSA region is different from the others as it is the only region where urbanization has occurred without industrialization (APP, 2015, 2016).

Finally, the adverse effects of global warming have already started having an impact on SSA, which is manifested in the form of flooding, heat stress, and fire hazards (Akinleye, 2018). Further, progress in the provision of clean energy (Goal 7) could also help to achieve the goal of climate change (Goal 13), and invariably on health and poverty or sustainable communities (Goal 11) (World Energy Outlook, 2017). The assumption is that ascertaining the critical determinants of carbon emissions could help in designing and implementing effective environmental protection policies. Thus, the results of the study could lead to evidence-informed policy in curbing or mitigating the impact of climate change associated with the transportation industry.

2.0 Literature Review

2.1. Transport energy consumption and carbon emissions

Many models have been used to explain the energy- emissions relationship, the most popular, however, are the static IPAT and the more dynamic STRIPAT models, which suggest that environmental impact is driven by population (P), affluence (A), and technology (T). Transportation services can reduce travel costs and consequently improve population mobility, which is usually correlated with the emissions of carbon dioxide (Xie et al., 2017). The population distribution, however, determines whether transportation energy, for example, could have a negative or positive impact on the environment. Obviously, a sparser population will increase travel time and therefore lead to increased carbon dioxide emissions, while a denser population will lead to the opposite effect. At the same time, population density could also affect both the rate of economic growth and technology adoption and, therefore, on environmental quality.

According to Fujita and Thisse (2003), when there is a movement of an economy from dispersion to agglomeration, it will not only experience more growth, but also innovation is more likely to follow at a faster pace. This spatial integration leads to economic efficiency, which, in the long run, has benefits on the environment, as explained by Grossman and Kreuger (1993). The discussion here suggests that population growth per se is inadequate in explaining carbon emissions because the population structure, population density, and the overall urban form have their dynamics and could have different effects in different contexts (Zhu and Peng, 2012; Wang et al., 2014)

Empirically, Talbi (2017) examined the determinants of carbon dioxide emissions in Tunisia during 1980 - 2014 based on Autoregressive Distributed Lag (ARDL) estimation technique and find support for the Environmental Kuznets Curve (EKC). The results suggest that in both the short-run and long-run, urbanization increases carbon emissions; however, the impact declines over time. The argument is that in the short-run, large population movement to urban centres puts pressure on the environmental resources; however, with the improvements in technology and environmental education in the long-term, the negative impact of urbanization on the environment reduces over time. Wang et al. (2017) extend the literature by considering socio-demographic characteristics and report that people with full-time jobs and have high incomes produce more carbon emissions. In an earlier study of Tunisia, Shahbaz et al. (2015) show that both transport energy consumption and road infrastructure have a negative effect on the environment.

Considering ASEAN 5 countries, empirical results of Tang (2013) suggest that foreign direct investment (FDI) has negligible effects on carbon emissions; however, in the long run, transport energy consumption and economic growth increase carbon emissions. Rahman et al. (2017) examine emissions from road transport in Saudi Arabia and show that the per capita fuel consumption increases at higher rates compared to some other neighbouring countries. Likewise, Alshehry and Belloumi (2017) analyze the role of transport energy consumption on carbon emissions for Saudi Arabia from 1971 – 2011 using the ADRL estimation technique to show that the EKC is not valid. The results show that economic growth is significantly correlated with carbon emissions and transport energy consummation. Thus, economic growth has occurred at the expense of the environment.

Similarly, Xie et al. (2017) explored the role of transportation infrastructure on the emissions of carbon dioxide using data from 283 Chinese cities over a decade (2003-2013), and the findings reveal that carbon emissions increase with the expansion of transportation infrastructure. Zhang et al. (2018) used the STRIPAT framework to examine whether land-use planning could help to reduce carbon emissions. The results indicate that landscape patterns and land use planning have a significant impact on carbon emissions. Andres and Padilla

(2018) examine the case for the EU-28 over the period 1990-2014 using the STIRPAT model. The results show transport modes' share and energy sources' mix—as driving factors of carbon dioxide emissions. Likewise, Wang et al. (2017) compared China and India and provided evidence of the importance of urban form in explaining the energy - carbon dioxide nexus. The study's findings based on spatial analysis and Tobit models show that the increase of vehicle occupancy could reduce transport sector emissions by 20 to 50%, while a reduction in vehicle occupancy could lead to a rise of 33.33 to 66.67 %. In another comparative study of Japan and China, Luo et al. (2017) demonstrate that during trip generation rate, mode shift, and travel distance show a strong effect on the carbon emission increase. In China (Shanghai), high emission vehicles contributed around 35% of emissions in total, while the fuel efficiency effect reduced emissions by only 10%. A similar result is found in Japan (Tokyo), where lower emission vehicles and decreasing travel distance led to a reduction in carbon emissions.

For Pakistan, Balock and Saud (2018) use the ARDL technique to examine the determinants of carbon dioxide emissions over the period 1990 – 2015 and found that transport energy consumption and FDI significantly contribute to carbon emissions. This is consistent with Danish et al. 's (2018) study of Pakistan, which shows that FDI and transport energy consumption has positive and significantly related to carbon emissions. Chandran and Tang (2013), however, show that FDI is not significantly related to carbon dioxide emissions through transport energy consumption, and income substantially influences carbon emissions. In a related study of Asian economies, Timilsina and Shrestha (2009) find that income, population growth, and transportation energy intensity are the key determinants factors of carbon emission growth

Others have also studied the effects of private investment on carbon dioxide emissions. For example, Lin and Omoju (2017) examine the moderating role of private investment in the transport infrastructure and carbon emissions link for a panel data of eight Asian countries based on STIRPAT and Fully Modified Ordinary Least Squares (FMOLS) techniques. The findings of the study show that urbanization's effect is mixed, while income and population size worsen the environment, but advances in technology reduce transport emissions. In a related study of OECD countries for the period 1995 – 2014 based on ARDL techniques, Neves et al. (2017) show that investment in rail infrastructure helped to reduce fossil fuel consumption and subsequent environmental pollution. However, the findings indicate that fossil fuel use boosted economic growth.

2.2 Urbanization and carbon emissions

Three main theoretical perspectives are generally used to explain the dynamic relationships between urbanization and the quality of the environment, including the compact city theory (CC), urban environmental transition theory (UET) and ecological modernization theory (EM) (see Poumanyvong & Kaneko, 2010; Sadorsky, 2014). More specifically, the CC and UET theories highlight the linkages between positive externalities of urbanization on the environment. It posits that while increasing urbanization results in overcrowding and rising congestions, which is strongly associated with increased carbon emission (Burton, 2000; Capello & Camagni, 2000; Breheny, 2001; Poumanyvong & Kaneko, 2010; Rudlin & Falk, 1999), it also reinforces policymakers to implement policies aimed at curtailing environmental pollution (Poumanyvong & Kaneko, 2010). A proponent of the EM theory, on the other hand, argues that the magnitude of environmental problems differs at various stages of city development (McGranahan, 2010). In particular, the theory depicts that the initial states of economic development lead to higher pollution through increasing production. However, as the wealth of cities improves, the extent of environmental pollution diminishes owing to structural change, technological improvement, and environmental regulation (Poumanyvong & Kaneko, 2010; Sadorsky, 2014). From the theoretical arguments, the net effect of urbanization on the environment cannot be determined *a priori* and therefore need for empirical studies. This necessitates our study

Though some empirical studies have been conducted, however, the findings from these studies are inconsistent. For instance, Wang et al. (2017) examined the determinants of carbon dioxide emissions in China over the period 1996-2010 based on the STIRPAT model. The findings show that urbanization and industrialization led to environmental pollution, but services and technology levels were pro-environment. The authors conclude that effective spatial planning and traffic organization are critical in reducing carbon emissions. Liu et al. (2017) investigate the case for 386 Norwegian municipalities from 2006-2009 using the STIRPAT framework and show support for the EKC. The results show that urban form matters in explaining environmental pollution. Notably, the authors show that the effect of urbanization on the environment is moderated by the urban density such that marginal increases in more densely populated areas were associated with reduced road transport energy use per capita. Fang et al. (2015), in a study of 289 Chinese cities report that population and urbanization rate was significantly related to air quality. The results, however, did not find support for the view that economic growth and the extent of urban land use detrimental effects on the environment.

Sardosky (2014) employed the techniques that allow for heterogeneous slope coefficients and cross-section dependence for emerging economies and find that urbanization's impact on carbon emissions was not robust. The results, however, indicate that energy intensity and affluence were significant and positively related to carbon dioxide emissions. On the other hand, Lin and Benjamin (2017) investigate the determinants of carbon emissions in China and report that urbanization's impact was far less than variables like energy and carbon intensity. It is worth mentioning that the effect of urbanization differed across different distributions of carbon emissions. However, Song et al. (2018) investigate the role of urbanization on air quality based on Chinese data from 2005 – 2010 and report that urbanization promoted growth at the expense of the environment. In a related study of China from 2008 – 2015.

The findings of the studies reviewed show that context matters in explaining the carbon dioxide emissions dynamics. Accordingly, we examine the case of SSA, where there has been a dearth of literature as it relates to transport energy emissions, using techniques that control for endogeneity and heterogeneity to improve consistency of the estimates.

3.0 Methodology and Data

3.1 Specification of the model

This study modifies the model of Abid (2016) and Tamazian, Chousa, and Vadlamannati (2009) to examine the impact of transport energy consumption and urbanization on carbon emissions. Thus, carbon emission (*ln*CO_2) is specified as a function of income (*lnrgdpc*), the squared of income (*lnrgdpc*^{2}), transport energy (*lntransenergy*) and urbanization (*lnturpopg*). Therefore, the empirical model to be estimated is given in Eq. (1):

$$lnCO_{2it} = \beta_1 + \beta_2 lnGDP_{it} + \beta_3 lnGDP^2{}_{it} + \beta_4 lntransenergy_{it} + \beta_5 lnturpopg_{it} + \emptyset_1 X_{it} + \theta_t + v_i + \varepsilon_{it} \qquad (1)$$

Where $i = 1 \ldots \ldots 19$ and $t = 1980 \ldots \ldots 2011$, all the control variables which have a potential effect on carbon emissions are captured in X,$v_i$is an individual specific effect, θ_t is fixed time effect, and ε is the stochastic error term. Following previous literature, the study controls for other explanatory variables such as population (*lnpop*), foreign direct investment (*lnfdi*), electricity consumption (*lnelec*) and agriculture (*lnagric*), which have a significant influence on carbon emissions (see Ahmed, Rehman, & Ozturk, 2017; Lee, 2013; Ren, Yuan, Ma, & Chen, 2014). We further control for institutions in our model, as has an essential effect on carbon emissions in developing countries (see Abid, 2017; Acheampong, Adams & Boateng, 2019; Tamazian et al., 2010). The dynamic fixed effect model and instrumental variable generalized method of moment (IV-GMM) models are the econometric models used for estimating Eq. (1). The IV-GMM was used to control for endogeneity, while the dynamic fixed effect model was used to capture the dynamic nature of the empirical model.

3.2. Data

The study examines the effect of transport energy consumption and urbanization on carbon dioxide emission for 19 sub-Saharan African countries over 31 years (1980-2011)[1]. The

[1]The data is limited between 1980-2011 because at the time of writing the paper, the transport energy consumption was up to 2011.

countries included in the study are Angola, Benin, Botswana, Cameroon, Congo, Dem. Rep. Congo, Rep. Cote d'Ivoire, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Senegal, South Africa, Sudan, Tanzania, Togo, Zambia, and Zimbabwe. These countries were selected based on data available on transport energy consumption.

Tables 1 and 2 provide the data description and the correlation matrix, respectively. Table 2 shows that multicollinearity is not an issue.

Table 1: Data source and descriptive statistics

Variable	Proxy	Codes	Mean	Sd	Min	max	Source
Carbon emissions	Carbon emissions measured in kiloton	lnco2kt	8.381	1.345	6.009	13.129	WDI
Economic growth	GDP per capita	lnrgdpc	7.099	0.959	5.098	9.447	WDI
Electricity consumption	Electric power consumption	lnelec	5.207	1.315	2.866	8.472	WDI
Population	Total population	lnpop	16.207	1.115	13.500	18.316	WDI
Foreign direct investment	Net inflow as a share of GDP	lnfdi	0.121	1.719	-8.508	3.693	WDI
Agriculture	Agriculture as a ratio of GDP	lnagric	2.864	0.808	0.603	4.156	WDI
Institutions	Regulation	Regulation	5.699	0.957	3.210	7.800	Gwartney, Lawson, & Hall, 2014
Urbanization	Total urban population growth	lnturpopg	1.374	0.408	-1.242	2.660	WDI
Transport energy	Road sector energy consumption	lntransenergy	5.953	1.132	3.594	9.689	Data market[2]

Note: WDI =World development indicators (World Bank, 2019)

[2] The dataset was sourced from: https://datamarket.com/data/set/14lz/road-sector-energy-consumption-kt-of-oil-equivalent#!ds=14lz!gmx&display=line

Table 2: Correlation Matrix

	lnco2kt	lnrgdpc	lnelec	lnpop	lnfdi	lnagric	regulation	lnturpopg	lntransenergy
lnco2kt	1								
lnrgdpc	0.439	1							
lnelec	0.665	0.735	1						
lnpop	0.479	-0.482	-0.113	1					
lnfdi	-0.164	0.0886	0.0442	-0.167	1				
lnagric	-0.406	-0.721	-0.729	0.370	-0.191	1			
regulation	0.458	0.508	0.440	0.0534	0.164	-0.514	1		
lnturpopg	-0.333	-0.125	-0.400	-0.139	-0.0729	0.282	-0.0189	1	
lntransenergy	0.880	0.216	0.471	0.643	-0.111	-0.276	0.513	-0.276	1

4.0 Empirical results

The baseline results are estimated using the IV-GMM results presented in Table 3. The findings reveal that economic growth has broadly insignificant impact on carbon, while its squared term remains positive in all the models, except in model 1. Our findings invalidate the EKC hypothesis in SSA and confirms previous findings such as those by Acheampong (2019), Stern (2001), and Acheampong, Amponsah, and Boateng (2020). The study finds that increased electricity consumption has a significant positive impact on carbon emissions. Although not surprising in the case of SSA, the cultivation of electricity for human use harm the environment due to the techniques employed in generating electricity by energy companies. For instance, the factor that predominantly dominates the generation of electricity is coal, which is much more environmentally harmful or problematic. Even though there is no dispute that some quantity of carbon naturally exists in the earth's atmosphere, existing studies show that coal releases a substantial amount of greenhouse gases, particularly carbon into the atmosphere (Acheampong, 2018; Ang, 2007; Apergis and Payne, 2009).

The results also suggests that rising population size worsens environmental quality as increased population exerts pressure on limited resources through high demand for private and public facilities and on the environment through poor waste disposal. Foreign direct investment reduces carbon emissions, while agricultural production significantly increases carbon emissions. The role of foreign direct investment in reducing carbon emissions supports the pollution-halo effect, which suggests the role of FDI in promoting technological transfers and knowledge spillover would result in improving environmental quality. This result is consistent with the findings of Adams et al. (2019) and Pao and Tsai (2011). The estimated effect of regulation—a measure of institutional quality—shows a negative and significant direct association between regulatory quality and environmental quality (see Acheampong et al., 2019). This implies that effective environmental regulation is critical for improving environmental quality. This result is inconsistent with the findings of previous studies that claim that regulations exert an insignificant effect on carbon emissions in sub-Saharan Africa (Acheampong and Dzator, 2020).

Regarding our variables of interest, the study finds that urbanization reduces carbon emissions, which contradicts previous argument that increase in urbanization leads to an increasing rate of carbon emissions and health hazards (see Martinez-Zarzoso and Maruotti, 2011; Song et al., 2018). The inconsistency of urbanization on carbon emissions due to the estimation techniques further adds to the argument of Adams and Acheampong (2019) and Sadorsky (2014) that depending on the estimation techniques, urbanization could have either a negative or a positive effect on carbon emissions. The inconsistency in the results regarding the rule of urbanization on carbon emissions is explained by the EM theory, which posits that the magnitude of environmental problem vary substantially at various stages of economic development (see McGranahan, 2010). Besides, our Adams and Acheampong (2019) and Sadorsky (2014) argue that the lack of consensus regarding the role of urbanisation in carbon emission is explained by differences in modelling techniques and context.

Table 3: IV-GMM results (Dependent variable: Carbon emissions)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Economic growth	1.069**	0.164	0.150	0.566	-0.226	-0.030	0.376	-0.023
	(0.507)	(0.376)	(0.375)	(0.375)	(0.394)	(0.664)	(0.383)	(0.397)
Economic growth squared	-0.003	0.043*	0.045*	0.018	0.041*	0.049	0.028	0.056**
	(0.032)	(0.024)	(0.024)	(0.024)	(0.024)	(0.030)	(0.024)	(0.025)
Electricity consumption	0.364***	0.258***	0.245***	0.216***	0.243***	0.249***	0.273***	0.244***
	(0.040)	(0.035)	(0.039)	(0.037)	(0.037)	(0.044)	(0.035)	(0.037)
Population	0.976***	0.444***	0.450***	0.466***	0.444***	0.446***	0.443***	0.442***
	(0.033)	(0.039)	(0.040)	(0.037)	(0.038)	(0.039)	(0.038)	(0.039)
Foreign direct investment	-0.075***	-0.050***	-0.049***	-0.045***	-0.041***	-0.051***	-0.042***	-0.051***
	(0.017)	(0.013)	(0.014)	(0.015)	(0.014)	(0.014)	(0.014)	(0.013)
Agriculture	0.179***	0.293***	0.301***	0.397***	0.357***	0.286***	0.321***	0.282***
	(0.059)	(0.059)	(0.060)	(0.064)	(0.063)	(0.062)	(0.058)	(0.059)
Regulation	-0.000	-0.144***	-0.143***	-0.093***	-0.105***	-0.140***	-0.696***	-0.308***
	(0.038)	(0.027)	(0.027)	(0.030)	(0.032)	(0.030)	(0.131)	(0.109)
Urbanisation	-0.196**	-0.177***	-0.339*	1.967***	-0.181**	-0.716	-0.162**	-0.893*
	(0.079)	(0.068)	(0.182)	(0.507)	(0.072)	(1.488)	(0.071)	(0.496)
Transport energy consumption		0.627***	0.629***	1.067***	-0.008	0.636***	-0.016	0.641***
		(0.040)	(0.040)	(0.106)	(0.187)	(0.047)	(0.170)	(0.041)
Urbanization squared			0.065					
			(0.061)					
Urbanization × Transport energy consumption				-0.390***				
				(0.091)				
Economic growth × Transport energy consumption					0.079***			
					(0.021)			
Urbanization × Economic growth						0.074		
						(0.200)		
Regulation × Transport energy consumption							0.098***	
							(0.023)	
Regulation × Urbanisation								0.127
								(0.083)
Constant	-17.096***	-7.081***	-7.082***	-11.825***	-4.070**	-6.050*	-4.380***	-5.464***
	(2.067)	(1.544)	(1.540)	(1.910)	(1.665)	(3.294)	(1.594)	(1.922)
Observations	382	382	382	382	382	382	382	382
R^2	0.868	0.916	0.917	0.924	0.920	0.917	0.920	0.918
j	1.092	0.768	0.509	0.744	0.951	0.732	0.637	0.442
jp	0.296	0.381	0.476	0.388	0.329	0.392	0.425	0.506
F-statistics	1361.919	1348.659	45.230	6.171	1338.107	1.804	1316.751	4.335

Heteroscedasticity robust standard errors in parentheses. J is Hansen J-statistics; jp is the p-value of Hansen J-statistics. F-statistics is the Cragg-Donald/Kleibergen-Paap F-statistics for weak instrument identification. The probability value for the Hansen J-statistics suggests that instruments are not over-identified while the F-statistics suggests the instrument is not weak. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Besides urbanization, the estimated coefficient for transport energy consumption is positive and statistically significant. This result is in line with previous findings that carbon emissions increase with the expansion of transportation infrastructure (see Xie et al., 2017). The cause of this increasing rate in carbon emissions in the transport sector is car transportation, which accounts for approximately half of all transport emissions. In fact, in SSA, cars emit more emissions than other forms of transportation due to the relatively high demand for road transport. In effect, road transportation burns more petroleum, which tends to increase the rate of emissions. Additionally, the absence of strict mandatory emissions standards across SSA countries has exacerbated the problem since cars mostly purchased or sold in the region are second hand or used from developed countries.

We, further, examine the interaction effects among the key variables of interest (see Models 4- 8). First, we include the interactions between urbanization and transportation energy consumption to see how the demand for transport service in the urban sector influences the quality of the environment in SSA. From the results, the estimated coefficient for interactions between urbanization and transportation energy consumption is negative and significant. The plausible policy implication is that improving the efficiency of urban infrastructures will reduce energy use in the transport sector, thereby reducing carbon emissions. The interactive effect between transportation energy consumption and economic growth is positive and significant, which supports the arguments by Alshehry and Belloumi (2017) and Xu and Lin (2015) that emissions from the transport sector are linked to economic growth; therefore the extent to which economic growth pollutes the environment is reinforced by the increasing quantity of nitrous oxides emitted from the transport sector into the atmosphere.

Urbanization moderates the impact of economic growth to increase carbon emissions. From the urban agglomeration theory, urbanization could boost economic growth through technological development and knowledge spillover, thereby increasing carbon emissions. The results also suggest that regulation moderates transport energy consumption to increase carbon emissions, suggesting that poorly regulated transport systems in SSA could worsen the quality of the environment. The interactive effect between regulation and urbanization is insignificant. As a robustness checks, the study employed a dynamic fixed effect model to examine the dynamic behaviour of carbon emission in respond to changes transport energy consumption and urbanizations. The estimated results are presented in Table 4 and the result vary, in some cases, in signs and magnitude since the fixed effect model does not account for endogeneity.

Table 4: Dynamic fixed effect results (Dependent variable: Carbon emissions)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Carbon emissions lag	0.655***	0.627***	0.627***	0.626***	0.621***	0.620***	0.622***	0.626***
	(0.060)	(0.054)	(0.054)	(0.054)	(0.054)	(0.051)	(0.057)	(0.053)
Economic growth	0.440	0.723*	0.676	0.723	0.769*	0.447	0.759*	0.498
	(0.362)	(0.396)	(0.430)	(0.432)	(0.361)	(0.366)	(0.391)	(0.440)
Economic growth squared	-0.010	-0.029	-0.026	-0.030	-0.009	-0.014	-0.032	-0.012
	(0.026)	(0.026)	(0.029)	(0.029)	(0.027)	(0.023)	(0.026)	(0.030)
Electricity consumption	0.275***	0.201***	0.203***	0.199***	0.202***	0.226***	0.202***	0.210***
	(0.079)	(0.061)	(0.061)	(0.062)	(0.063)	(0.068)	(0.059)	(0.062)
Population	0.278***	0.264***	0.265***	0.263***	0.268***	0.268***	0.263***	0.260***
	(0.062)	(0.047)	(0.047)	(0.045)	(0.054)	(0.049)	(0.045)	(0.049)
Foreign direct investment	0.008*	0.005	0.005	0.007	0.005	0.004	0.005	0.005
	(0.004)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Agriculture	-0.012	0.029	0.026	0.025	0.008	0.010	0.031	0.017
	(0.041)	(0.041)	(0.043)	(0.039)	(0.040)	(0.044)	(0.042)	(0.044)
Regulation	-0.028**	-0.048***	-0.047***	-0.049***	-0.045***	-0.041***	-0.090	-0.089***
	(0.011)	(0.010)	(0.010)	(0.010)	(0.009)	(0.010)	(0.059)	(0.027)
Urbanisation	0.069**	0.068***	0.044	-0.162	0.052**	-0.445*	0.070***	-0.124
	(0.031)	(0.022)	(0.047)	(0.126)	(0.022)	(0.240)	(0.020)	(0.108)
Transport energy consumption		0.111**	0.109**	0.051	0.448***	0.096**	0.074	0.103**
		(0.039)	(0.040)	(0.059)	(0.114)	(0.042)	(0.066)	(0.041)
Urbanization squared			0.011					
			(0.021)					
Urbanization × Transport energy consumption				0.041*				
				(0.022)				
Economic growth × Transport energy consumption					-0.051***			
					(0.017)			
Urbanization × Economic growth						0.070*		
						(0.033)		
Regulation × Transport energy consumption							0.007	
							(0.011)	
Regulation × Urbanisation								0.034
								(0.021)
Constant	-5.633***	-6.408***	-6.281***	-6.006***	-7.590***	-5.268***	-6.268***	-5.383***
	(1.416)	(1.447)	(1.529)	(1.518)	(1.382)	(1.267)	(1.470)	(1.598)
Observations	395	395	395	395	395	395	395	395
R^2	0.841	0.846	0.846	0.847	0.848	0.848	0.846	0.847
rho	0.764	0.605	0.616	0.610	0.720	0.713	0.597	0.667
rmse	0.154	0.151	0.151	0.151	0.150	0.151	0.151	0.151
F-statistics	476.791	483.533	921.854	376.753	655.373	7065.357	376.046	1943.637

Heteroscedasticity robust standard errors in parentheses, rmse is the root mean square error. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.1 Robustness Analysis

Due to the difference among the countries, the sample mean could be different from individual country mean. We, therefore, conduct further analysis by predicting the impact of the variables under consideration on carbon emissions for each country. We used the estimated results in Table 4 to predict the effect of the variables on carbon emissions for each country.

4.1.1 Predicted impact of transportation energy consumption on environmental quality

Figure 1 presents the predicted effect of transport energy consumption by taking the partial derivative of carbon emissions concerning transport energy consumption. The estimated result in Fig.1 reveals significant differences regarding the effects of transport energy consumption across the sampled countries when evaluated at the mean of transport energy consumption. Specifically, we find that the estimated impact ranges from 4.183 to 9.254, with Eritrea as the SSA country having the least predicted effect of transport energy consumption on carbon emissions. In contrast, South Africa has the highest predicted impact value. In other words, the value of the predicted effect of transport energy consumption on carbon emissions for South Africa is 9.254, signifying that increased congestion and pollution from the transport sector accounts for 9.254 % rise in carbon emissions. Moreover, the results imply that a percentage change in carbon emissions owing to a percentage change in transport energy consumption is higher in South Africa relative to the remaining countries under consideration. Other countries with relatively higher predicted impacts are Sudan (7.004), Kenya (6.720), Ghana (6.550), and Cameroon (6.389).

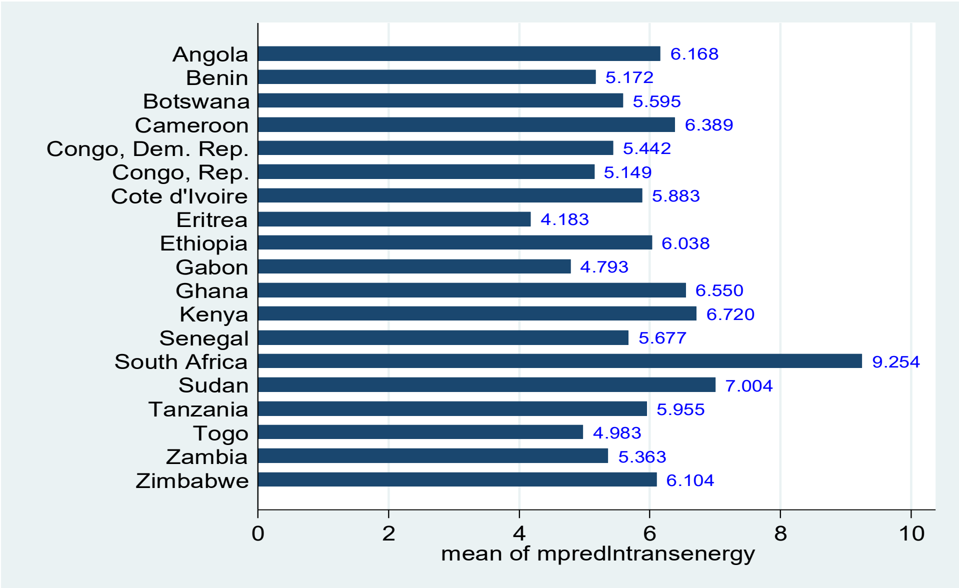

Fig. 1 Predicted impact of Transportation energy consumption on carbon emissions by country

4.1.2 Predicted impact of urbanization and electricity consumption on environmental quality

Fig.2 shows the predicted values of electricity consumption and urbanization on carbon emissions. It can be observed that while there is a wide variation between for the predicted value of electrical energy consumption across the countries, we find a relatively close value for the impact of urbanization on carbon emissions. More specifically, the predicted value for electric energy consumption on emissions is higher for South Africa, while the effect is notably lower for Ethiopia. On the contrary, South Africa and Eritrea have the least effect of urbanization on pollution, with Angola having the highest effect on emissions.

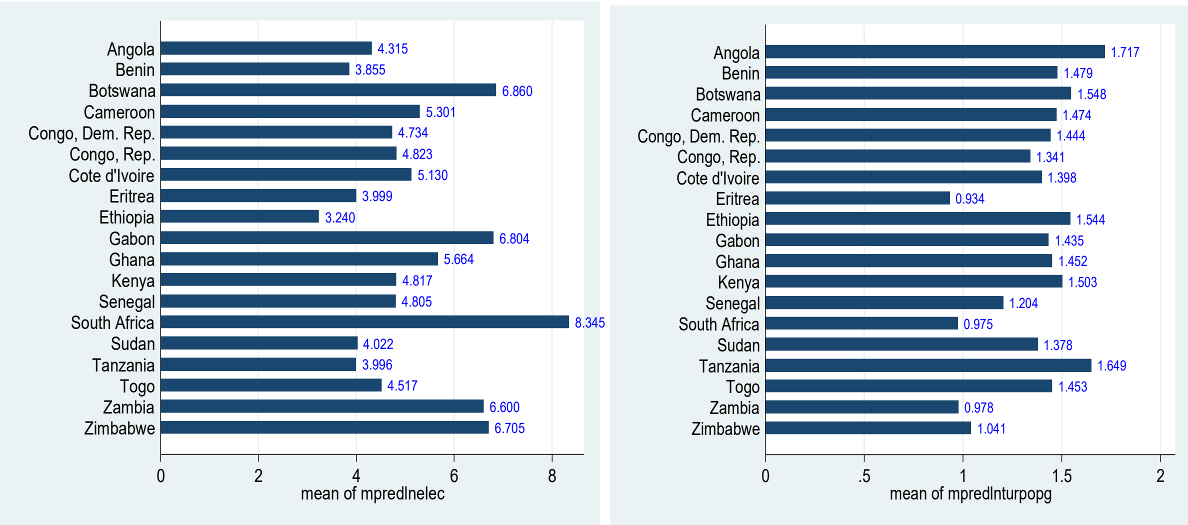

Fig.2 Predicted impact of electricity consumption and urban population growth on carbon emissions by country

4.1.3 Predicted impact of FDI and Population size on environmental quality

Fig.3 reveals significant heterogeneity in the predicted values concerning the effect of foreign direct investment on carbon emissions. The effect is especially negative for Benin, Cameroon, Ethiopia, Ghana, Kenya, South Africa, Sudan, Tanzania, and Zimbabwe. This suggests that the flow of FDI to these countries is not pollution-haven. Contrarily, the predicted value of *lnfdi* reveals that activities of foreign investors across countries such as Angola, Cote d'Ivoire, and Zambia are harmful to the environment.

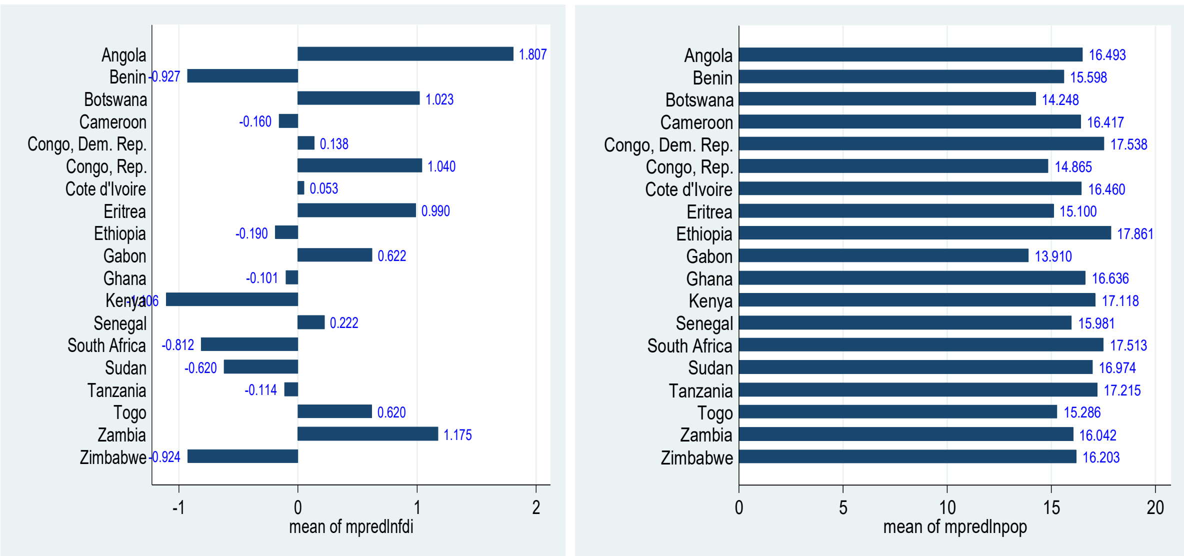

Fig.3 Predicted impact of FDI and Total population growth on carbon emissions by country

4.1.4 Predicted impact of Agricultural sector and economic growth on environmental quality

The result displayed in Fig. 4 shows the effect of agricultural output and economic growth on carbon emissions. The figure reveals the positive impacts of agricultural output and economic growth on carbon emissions for all the countries. More specifically, since the majority of countries are mostly agrarian economies, the findings imply that increase agricultural sector production aimed at expanding the output of these countries increases the extent of environmental destruction. It is also revealed by Fig.4 that countries such as Ethiopia (3.869), Ghana (3.678), and Dem. Rep. of Congo (3.440) has a more significant impact on carbon emissions than other economies such as Botswana (1.345) and South Africa (1.294) that exerts relatively less effect on the environment owing to increasing agricultural output. Regarding economic growth, increased economic growth tends to increase the intensity of carbon emissions for all countries, with Gabon and South Africa having the highest impact.

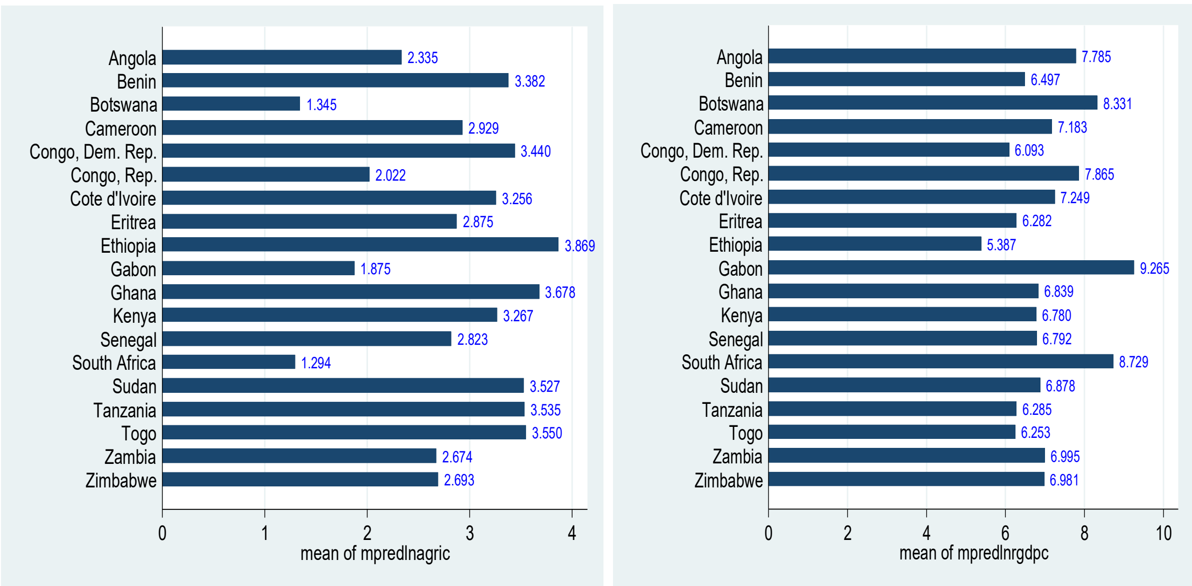

Fig.4 Predicted impact of Growth in Agricultural output and economic growth on carbon emissions by country

5.0 Conclusions and Policy Implications

The role of transportation and urbanization in contributing to carbon emissions cannot be underestimated. Prior studies have generally examined the linkages between carbon emissions and energy consumption in developing countries. However, not much attention has been given to the effect of transport energy consumption and urbanization. This study contributes to the debate on sustainable transportation and urban development, focusing on the impact of transport energy consumption and urbanization on carbon emissions in sub-Saharan Africa. Using the IV-GMM techniques to estimate our models, the following conclusions emerge from the study. First, the study finds that urbanization reduces carbon emissions in SSA. Second, transport energy consumption worsens carbon emissions in the region. However, improving the efficiency of urban infrastructures and reduction in transport sector emissions have inhibiting impact on carbon emission in SSA. The study found that while regulations and foreign direct investment reduce carbon emissions, electricity consumption, agriculture output, and population worsen carbon emissions. Finally, the study established that the impact of transport energy consumption, urbanization, and other control variables on carbon emissions vary quite dramatically across SSA countries.

Policy Implications

Several policy implications emerge from our findings. In particular, given the adverse impact of transport energy consumption on environmental quality in SSA, we argue for mandatory emissions standards to be imposed on the importation of used cars to SSA countries that emit more than their equivalents in developed countries. Such strict standards, when enforced, would reduce not only the degree of greenhouse gas emissions but would also reduce the risks of SSA countries becoming dumping grounds for less efficient cars that have outlived their usefulness in overseas countries. Another implication of the study is that drastic policies must be implemented to reduce the ever-increasing population in urban areas across the region. As explained by the urban environmental transition and ecological modernization theories, higher urbanization damages the environment as it puts pressure on energy-intensive products—such as automobiles—that increased carbon dioxide emissions. Moreover, the quality of institutions or regulations should be improved to moderate economic activities that are more prone to affect the environment adversely. Finally, policymakers should rethink of alternative clean energy sources to generate electricity since the use of fossil fuels has adverse consequences on environmental quality. While the above measures are key to reducing the magnitude of environmental destruction, country-specific characteristics should be considered when implementing carbon emissions reduction policies.

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