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Heterogeneous Assessment of Urbanisation, Energy Consumption and Environmental Pollution in Africa: the Role of Regulatory Quality

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Abstract

The pace of urbanisation, the intensity of energy consumption, and the quality of environmental regulation level pose a severe threat to environmental sustainability in Africa. Hence, we examine the role of regulatory quality on environmental pollution through urbanisation and energy consumption channel in 33 African nations between 1996 and 2020. Our study considers cross-sectional dependence in Africa; as a result, we employ the Augmented Mean Group (AMG) method and Common Correlated Effect Mean Group (CCEMG) for a robustness check to analyse the panel series. The study finds that (i) urbanisation increases environmental pollution, (ii) energy consumption accelerates environmental degradation, (iii) regulatory quality can partially mediate pollution in Africa via urbanisation and energy consumption channels, and (iv) The interaction of regulatory quality with urbanisation and energy consumption, respectively reduce environmental pollution establishing a moderation effect. The study suggests that African countries tighten environmental regulatory policies to lessen carbon emissions and drive environmental sustainability towards achieving carbon neutrality by 2050.

Keywords: Heterogeneous, Urbanisation, Energy consumption, Environmental pollution, Regulation, Africa

JEL Codes: C20, R00, Q40, Q52, L52, N57

1. Introduction.

The negative impact of environmental pollution is a global problem. According to the World Health Organization (WHO) (2022), every year, air pollution causes 7 million premature deaths worldwide. Similarly, one in six deaths worldwide is attributable to environmental pollution (Alberts, 2022). Due to the glaring negative impacts of environmental pollution on human life, researchers and policymakers are searching for the drivers of pollution globally, regionally, and nationally to suggest policy solutions to environmental problems. Moreover, because of the severity of climate change due to environmental pollution, the United Nations Global Agenda (goal 13) by 2030 highlights the need for climate actions worldwide to promote environmental sustainability (United Nations, 2020). However, Solarin et al. (2018) and Rahman & Alam (2021) have argued that energy use and urbanisation expansion are the leading cause of environmental problems worldwide.

In this respect, energy consumption is increasingly considered a major driver of environmental pollution globally (Solarin et al., 2018; Bello et al., 2018; Maduka et al., 2022). Also, the pace of urbanisation in recent decades due to global population growth seriously threatens environmental quality (Dimwobi, 2021). This is because urbanisation expansion increases the demand for productive and consumptive energy. Furthermore, urbanisation also necessitates deforestation to provide housing for the bubbling population in the urban area. This also necessitates cutting economic trees as a fuelwood source to meet energy cooking needs. However, as urbanisation expands, economic activities increase (Bello et al., 2018). The aftermath of these circumstances collectively exacerbates the carbon footprint, degrading the environment just as the Environmental Kuznets Curve theory emphasises that a rise in economic activities drives environmental deterioration. Moreover, effective government regulations can alter the possible impact of urbanisation spread and energy use on the environment by implementing sustainable energy and green city policies. However, to what extent can this regulatory quality improve environmental sustainability in Africa via urbanisation and energy use channels, owing to weak regulation in Africa?

According to Salahuddin et al. (2018), demographic expansion is a crucial driver of urbanisation and its concomitants. Africa's rapidly growing population has made the continent one of the fastest regions with high urbanisation rates globally, with about 3.58% annual urban growth rate (United Nations Economic Commission for Africa (UNECA), 2021). This rapid population growth can trigger the environmental population via several primary channels. First, urbanisation promotes the emergence of new towns and the demand for housing, necessitating the falling of trees. This depletion of forests leads to climate change and environmental degradation (Adams andKlobodu, 2017; Mignamiss and Djeufack, 2021; Armeanu et al., 2021). Secondly, urban growth leads to an increase in commercial activities, household lighting, and transportation. These undertakings thrive on the intensive use of fossil energy leading to carbon emission discharge in the atmosphere and, consequently, environmental pollution (Behera & Dash, 2017; Effiong, 2017; Salahuddin et al., 2018; Dimnwobi et al., 2021). Hence, with the pace of urban growth and environmental concern in Africa, it is pertinent to analyse the effect of urbanisation on environmental pollution to design sustainable urban growth policies for Africa.

Furthermore, urban economics literature documents that as urbanisation increases, modernisation and industrial growth rise, increasing energy consumption (Beheraand Dash, 2017). The intensity of energy use due to urban expansion and industrialisation can potentially portend negative environmental externalities especially utilising fossil fuel resources. African countries have plenty of fossil energy resources, making them available to fire economic activities (Hanif, 2018; Maji & Suleiman, 2019). For instance, the BP 2021 statistical review revealed that from 2017 to 2019, primary energy use and CO2 emission increased in Africa from 19.0EJ to 19.8EJ and 1327.91MT to 1364.53MT, respectively. Nonetheless, despite Africa's minimal contribution to global carbon emissions relative to other areas, such as North America, Europe and Asia, emissions of CO2 in the region will continue to rise and reach troubling proportions in the next decade (Dimnwobi et al., 2021). This gloomy prognosis can become a reality given the emerging institutional and socio-economic initiatives in the continent geared to spark industrialisation and economic growth (Dong et al., 2018; Aluko and Obalade, 2020; Avom et al., 2020; Okafor et al., 2022).

However, the extent to which African nations can control environmental pollution from urban expansion and the intensity of energy use depends on the effectiveness of environmental regulation (Dimnwobi et al., 2021; Maduka et al., 2022). Goel et al. (2013) emphasised that effective environmental regulation empowers institutions to checkmate the activities of economic agents driving urbanisation and energy intensity that are harmful to the environment. This implies that the laxity of environmental regulation can expose the environment to danger. Moreover, Mesagan and Olunkwa (2022) noted that regulation in Africa is generally weak. This may hinder effective environmental regulation in the region needed to drive sustainable urbanisation and energy consumption. In this respect, it is important to assess whether the quality of regulation in Africa can guarantee environmental sustainability in the region.

Therefore, the main thrust of this study is to determine how African countries can guarantee environmental quality via a sound and well-articulated regulatory quality medium. Notably, we investigate the effect of urbanisation and energy consumption on pollution in Africa. We further assessed regulatory quality's mediating and moderating role on environmental pollution via urbanisation and energy consumption linkage in Africa. The significant contribution of this study is fourfold. First, the study makes a substantial contribution to the environmental pollution discourse in Africa, considering the role of environmental regulation in controlling pollution via the rising urbanisation rate and energy consumption in Africa. Second, unlike previous studies that adopted institutional quality (Goel et al., 2013), political stability (Al-Mulali and Ozturk, 2015), democracy and bureaucracy (Adams and Klobodu (2017), and control of corruption (Maduka et al., 2022) we utilise the regulatory quality index because it empirically reflects public opinions of a government's capacity to design and enforce effective rules and regulations. Thirdly, we interact urbanisation and energy consumption with regulatory quality to establish a double-barrel approach to tackling pollution in Africa since pollution from the urban centre is fast rising. Fourth, in terms of methodological contribution, contrasting with related studies, we consider the issue of cross-sectional dependence (CD) due to the heterogeneous nature of African nations by employing the recent Augmented Mean Group (AMG) methodology to generate consistent and efficient estimates for policy prescription. Furthermore, the contribution of our study fills the vacuum in the studies of Mesagan and Olunkwa (2022) by considering the effect of urbanisation expansion on the energy-pollution channel because if the pace of urbanisation in Africa is not watched and controlled, it will soon become the main environmental degradation channel in Africa. Urbanisation-led environmental deterioration was one of the focal points of discussion at COP26, and it was estimated that if the current urbanisation growth rate is sustained, CO2 emission in Africa will expand by 30% in the next decade (Freehill Report, 2021). This poses a gloomy picture of African environmental quality if not regulated; thus, the necessity to empirically assess the urbanisation-pollution nexus accounting for the role of regulatory quality. Additionally, unlike Mesagan and Olunkwa (2022), methodologically, our study accounted for cross-sectional dependence by using the novel AMG that is robust in the presence of CD to generate an estimate to guide inferences, but Mesagan and Olunkwa (2022) did not take biases of the pool mean group (PMG) into consideration even after confirming that African nations are cross-sectionally dependent. We have considered the heterogeneity of African countries, which further strengthens the robustness of our findings and our study's innovation.

Following the need for precision and ease of understanding, the remaining segments of the study follow as thus; 2. Empirical review 3. Methodology and theoretical framework 4. Empirical results, 5. Conclusion and policy prescription.

2. Empirical Review.

Numerous studies in the existing literature have beamed the searchlight on environmental quality, focusing on different determinants. In this regard, we review the existing literature in four segments as;

Urbanisation and Pollution Nexus

For instance, Effiong (2017) used the STIPAT model to assess the nexus between urban expansion and pollution in Africa between 1990 to 2010. The author employed the semi-parametric panel fixed-effects regression technique and established that urbanisation increased environmental pollution. For the same region, AdamsandKlobodu (2017) adopted a panel cointegration model and examined the connection between urbanisation and the political environment on environmental pollution. The study found that between 1970 and 2011, urbanisation increased pollution while political economy indicators (Democracy and Bureaucracy) caused pollution to fall. Also, the study by Salahuddin et al. (2018) found that urbanisation increased environmental degradation in 44 SSA nations from 1984 to 2016 using the panel regression model. Additionally, the authors employed the Dumitrescu-Hurlin (DH) causality and checked the causal nexus between urbanisation and environmental pollution, and the result consolidated the panel regression estimate indicating that urbanisation caused environmental deterioration. More so, extending the scope of Salahuddin et al. (2018), Mignamiss and Djeufack (2021) assessed the effect of urbanisation on CO2 emission in Africa based on the method of 2SLS instrumental variables (2SLS-IV) and quantile regressions with IV from 1980 to 2016. The study accounted for the moderation of corruption control and democracy through urbanisation and pollution models. The authors showed that urbanisation increased carbon emissions in Africa, while the moderation of institutional variables (corruption control and democracy) revealed that urbanisation significantly reduced pollution in Africa.

Energy consumption and Environmental Pollution

In this segment of the review, Bastola and Sapkota (2015) studied the link between energy consumption and environmental degradation in Nepal using the ARDL bound test method. They found a long-run association between energy consumption, economic output and CO2 emissions between 1980 and 2011. Bello et al. (2018) adopted the vector error correction model for Malaysia and assessed the nexus between electricity consumption and CO2 emission. The result of the study indicated that hydroelectricity improved the environment while control factors (i.e. GDP and urbanisation) increased environmental damages between 1971 and 2016. However, Solarin et al. (2018) established a positive relationship between biomass energy use and carbon emission in 80 developing and developed economies using the system GMM and the Common Correlated Effect Estimator (CCE) methodologies. Contrariwise, Lee (2018) found a negative nexus between renewable energy and pollution between 1961 and 2012 for EU nations. Also, focusing on SANEM nations, Mesagan et al. (2020) employed the pooled mean group (PMG) technique and analysed the pollution phenomenon between 1990 and 2016. The result showed that energy consumption lowered short-run pollution while it increased long-run pollution for the panel.

Regulation and pollution linkage

Concerning this category of review, Samimi et al. (2012) analysed the overall effect of governance on environmental degradation in the Middle East and North African (MENA) countries between 2002 and 2007. The authors used the pooled ordinary least squares method for analysis. The empirical evidence showed that good governance increased environmental quality. Goel et al. (2013) considered corruption control and shadow economy as institutional variables for the same region and concluded that nations with good institutions lowered carbon emissions. Danish et al. (2019) captured environmental regulation with patents for environmental technologies and studied its mitigating role on Co2 emissions in BRICS from 1995 to 2016. The study relied on the FMOLS analysis method and confirmed that environmental regulation positively reduced carbon emissions in BRICS countries. More so, they concluded that environmental regulation supported the proposition of the EKC for the panel sample. Finally, Mesagan and Olunkwa (2022) included regulatory quality in their energy, financial development and environmental quality model for Africa between 1996 and 2017. They utilised the pooled mean group analytical method and confirmed that regulatory quality improved environmental quality in the region in short and long-run periods.

Energy use, urbanisation, regulation and pollution

In this last segment of the literature review, Al-Mulali and Ozturk (2015) assessed the ecological footprint (EFP) determinant in 14 MENA economies by considering urbanisation, energy use, political stability, industrial productivity and trade using the FMOLS. The study showed that the determinants deteriorated the ecological footprint except for political stability, which enhanced the environment between 1996 to 2014. Also, Behera and Dash (2017) studied the linkage between urbanisation, energy, and FDI on pollution between 1990 and 2012 in South and Southeast Asia. Using the Pedroni cointegration technique, the study found a positive linkage between energy, FDI and CO2 emission. Finally, Hanif (2018) decomposed energy into renewable and non-renewable, urbanisation and economic growth to model environmental pollution for 34 SSA nations. The study employed the system-GMM for the data analysis and revealed that between 1995 and 2015, fossil, solid wood fuel, urbanisation and increased carbon emissions, whereas renewable energy reduced CO2 energy. The study also established a U-shaped linkage between growth and carbon emissions.

Further, Khan et al. (2019) examined the environmental quality situation in Pakistan by assessing the effect of economic factors, globalisation and energy consumption on pollution. The study showed that energy consumption increased environmental distortion between 1971 and 2016. Also, they revealed that economic factors such as trade, financial development, and FDI increased environmental pollution, but innovation and urbanisation lowered carbon emissions. Nathaniel et al. (2020) analysed the environmental situation of coastal Mediterranean countries (CMCs) between 1990 and 2016. They employed the panel quantile regression approach and OLS on energy consumption, urbanisation, growth, FDI and carbon emission. The study found that energy consumption intensified environmental deterioration across all quantiles while growth and urbanisation had mixed pollution impacts. Nathaniel et al. (2020) also included financial development and growth in their renewable energy, urbanisation and environmental sustainability model for MENA countries. They revealed that urban expansion, economic prosperity and the financial sector worsened environmental pollution between 1990 and 2016. In addition, Adams et al. (2020) focused on transport energy and urbanisation's impact on CO2 emission in 19 SSA economies. The study showed that transportation energy use and urban growth hindered environmental sustainability in Sub-saharan Africa from 1980 to 2011.

In conclusion, the effect of urbanisation and energy use on environmental degradation is widely examined in the literature with conflicting findings. Perhaps, because of the study's sample, methodology, and scope. The mixed evidence requires an empirical investigation for Africa because Africa has the fastest urbanisation growth rate globally, with about 2.5% population growth rate. This socio-economic profile is a source of concern because as urban growth and population size rise, energy demand increases likewise, thereby impacting climate change. Hence, sound regulatory quality is needed to tackle the plausible impact of urban expansion and energy consumption on the environment. Therefore, unlike other studies in the literature, this study considers the role of regulatory quality in promoting environmental quality in Africa. Secondly, this study contributes to the literature by interacting urbanisation and regulatory quality, and energy consumption and regulatory quality to establish a double-barrel approach to tackle pollution in Africa. Thirdly, this study contributes to the theory by expanding the Environmental Kuznets Curve model to include energy use, urbanisation and regulatory quality. This is because the quality of government regulation can enhance the reversal of environmental degradation in the long run. And lastly, unlike existing studies, especially for Africa, this study makes a methodological contribution by considering cross-sectional dependence (CD) because of the heterogeneous nature of African nations. As a result, the study adopts the recent Augmented Mean Group (AMG) to generate consistent and efficient estimates for policy prescription.

2.1 Overview of Energy Consumption Regulation and Environmental Protection in Africa

This segment of the paper provides an overview of the regulatory quality in Africa in relation to energy consumption and environmental protection. According to Mesagan and Olunkwa (2022) and Afolabi (2023), regulatory quality is generally weak in Africa. This is not unconnected to the bane of institutionalised corruption and the unstable political atmosphere in the African region. Africa's regulatory quality index is the lowest based on GlobalEconomy (2022) report compared to other regions worldwide. For instance, in 2021, the regulatory quality index for Africa was -0.75 compared with Asia at -0.13, Europe at 0.9, North America at 0.21, and South America at -0.35 (GlobalEconomy, 2022). The low index depicts poor regulatory quality and the general weakness of regulation in Africa. Moreover, Akorli and Adom (2023) emphasised that regulatory quality weakness in any economy allows for the thriving of behavioural irregularities, whether market or non-market behaviour. This is because regulatory quality represents the extent to which the government design and implement rules and policies to control and govern people's actions. This action relates to how individuals interact and carry out their economic and non-economic activities, which evolve around production and consumption. Therefore, as regulation becomes effective in controlling people's economic actions, it also exacts control of energy use. However, since there is an agreement in the literature, i.e. Twerefou et al. (2019), Sharma et al. (2021), and Shi et al. (2023), that the intensity of energy use in the quest to satisfy the economic need is the hallmark driver of environmental degradation, it implies that the effectiveness of regulatory quality to control energy consumption invariably supports environmental promotions.

Furthermore, the development of regulatory instruments to control energy consumption is still at the rudiment in Africa. The major energy use regulation effort in Africa involves the African Energy Efficiency Programme (AEEP) and Energy Subsidy Reform (ESR). AEEP was developed by African Energy Commission (AFREC) with the support of the United for Energy Efficiency Programme (U4E) by the UN (African Energy Commission (AEC), 2023). The AEEEP aspires to control Africa's energy consumption, greenhouse gas emissions, and environmental pollution while ensuring that energy use is conservative and sustainable to meet millions of new customers and companies' energy needs. Moreso, AEC (2023) stated that aside from promoting energy conservation through consumption control, AEEP seeks to speed Africa's transition to more efficient electrical products, saving African consumers more than $175 billion by 2030 and averting the building of over 50 large (1 GW) power stations over the next two decades. According to AEC (2023), the implementation strategy of AEEP involves enhancing the management of energy efficiency programs at the national and regional levels, including a comprehensive legal framework for energy efficiency in the manufacturing sector, construction management, living activities, and energy-consuming equipment.

However, prior to the development of AEEP, national and subnational governments in Africa began to launch energy efficiency instruments for energy consumption regulation to conserve energy use and protect the environment from excessive carbon emission injection into the atmosphere (Chibuisi, 2019). For instance, Kenya in 2016 designed the energy regulation policy which is also known as Appliances Energy Performance and Labelling (AEPL). The regulation requires that all appliances manufactured in Kenya or imported carry energy-efficient labels. The label is to display the energy performance of the appliance. The essence is to control the energy consumption of households to promote conservation and reduce households' carbon footprint that deters the environment (See Energy Regulation Report, 2016). Also, in 2007 Egypt launched the Energy Efficiency and Environment Protection Framework (EEEPF) to control the energy consumption habits of industries domiciled in the nation to cut down on the industrial carbon footprint in Egypt (World Bank, 2010). Similarly, Egypt also established Egyptian Residential Buildings Energy Code (ERBEC) in 2006 to regulate household energy use and minimise the energy waste flowing from the residential sector (Hanna, 2015). South Africa also launched the

National Energy Efficiency Strategy (NEES) framework in 2005 and revised it in 2008 to promote sustainable energy development and energy use through efficient practices in South Africa. The regulation aimed to reduce energy use waste and protect the environment from emissions from the intensity of energy use (See Department of Minerals and Energy Report, 2008).

Furthermore, energy subsidy reform is the most recent regulation in Africa that is regulating energy consumption and lowering environmental costs. Energy subsidies represent a form of financial assistance governments offer to lower the price of energy distribution, production, and consumption for people, businesses, and industries (Al-Saidi, 2020). Economically, energy subsidies have historically been associated with promoting energy access, domestic energy production, and energy security, all of which can have broader favourable implications on economic and societal development (Whitley & Van der Burg, 2015). Several African countries have adopted energy subsidy regulations to promote energy access. Whitley & Van der Burg (2015) noted that in 30 Sub-Saharan African nations, estimates of fossil fuel subsidies, including those for electricity, were US$32 billion in 2013 but declined to US$26 billion in 2015. The decline in energy subsidies is attributed to subsidy regulation reforms due to the social and environmental cost of energy subsidies because subsidising energy means that more energy will be consumed, increasing carbon footprint per capita and thus stirring GHGs emissions leading to environmental degradation. More so, government spending on energy subsidy means that the government will be under the fiscal burden to expand investment in environmentally sustainable projects that enhance environmental protection. Hence, energy subsidy regulatory reform ongoing in Africa is lowering fossil fuel consumption and supporting environmental protection. For instance, on 27th May 2023, Nigeria announced the total removal and reform of fuel subsidies in Nigeria; following this reform, the Nigeria National Petroleum Commission (NNPC) announced that the average consumption of Petroleum Motor Spirit (PMS), which is the dominant source of energy across all the sector decline by 8.5 million litres daily (Nnodim, 2023).

Therefore, African countries are generally making efforts through regulatory design in regulating energy use intensity as a measure to averting the accumulation of GHG emissions even though the African continent contributes very minimally to GHG emissions. Twerefou et al. (2019) posited that such a regulatory framework effort is crucial for the African region to begin to checkmate the intensity of energy use because, as a continent with rapid population and urbanisation growth in no distance time, it will be major pollution effluent. Hence, the role of regulatory quality in Africa in controlling energy use is pertinent for environmental protection.

3. Theoretical Leaning and Methodology

Following Mesagan and Olunkwa (2022), we adopt the Environmental Kuznets Curve (EKC) hypothesis as the theoretical underpinning of this study. The EKC propose a U-shaped linkage between pollution and income growth. The emphasis is that as nations' income increases at the initial growth stage, environmental pollution rises; as income rises further, pollution declines (Andreoni and Levinson, 2001; Dogan and Seker, 2016; Mesagan et al., 2021). Further, Dogan and Seker (2016) and Maduka et al. (2021) emphasised that the EKC shows that nations eventually become wealthy to afford cleaner energy technologies and eco-friendly appliances, which promote environmental quality in the long run. Hence, the EKC assumes that environmental pollution is a quadratic function of income growth, and we present the mathematical equation as follows;

$$ENV_{it} = \alpha_0 + \alpha_1 Y_{it} + \alpha_2 Y_{it}^2 + \mu_{it} \tag{1}$$

In Eq. (1), ENV is environmental pollution, Y captures income level, which is the nation's initial income level, and Y^2 indicates a further increase in income of the economies. Therefore, the EKC expects the coefficient of Y to be positive and Y^2 negative (Maduka et al., 2022; Mesagan and Olunkwo, 2022). In addition, α_0 is the intercept, $\alpha_1 - \alpha_2$ are the slopes of the regression, μ is the stochastic error term, and *I* and *t* represent the series of the panel over the period.

Therefore, following the objectives of the study, we specify Eq. 2-4 by expanding Eq. (1) as thus;

$$ENV_{it} = \alpha_0 + \alpha_1 Y_{it} + \alpha_2 Y_{it}^2 + \alpha_3 EN_{it} + \alpha_4 URB_{it} + \alpha_5 POP_{it} + \alpha_6 TR_{it} + \alpha_7 FDI_{it} + \alpha_8 CAP_{it} + \mu_{it} \tag{2}$$

Eq. (2) captures the impact of urbanisation and energy consumption on environmental pollution. Where EN presents energy consumption, URB is urbanisation. Population (POP), trade openness (TR), foreign direct investment (FDI), and physical capital (CAP) are control variables in the model to control for possible variable bias (Dimnwobi et al., 2021; Mesagan et al., 2021). More so $\alpha_1 - \alpha_8$ are the regressions parameters. Other parameters in the model remain as defined earlier.

We then introduce the role of regulatory quality in Eq. (2) to form Eq. (3) to ascertain the mediating effect of regulation on pollution control in Africa as tested in the study of Sharma et al. (2021) Evans and Mesagan (2022) as follows;

$$ENV_{it} = \alpha_0 + \alpha_1 Y_{it} + \alpha_2 Y_{it}^2 + \alpha_3 EN_{it} + \alpha_4 URB_{it} + \alpha_5 REG_{it} + \alpha_6 POP_{it} + \alpha_7 TR_{it} + \alpha_8 FDI_{it} + \alpha_9 CAP_{it} + \mu_{it} \tag{3}$$

REG indicates regulatory quality, and the rest indicators are the same as explained. However, $\alpha_1 - \alpha_9$ are the coefficient estimates. Lastly, we interact urbanisation and regulatory quality (URB*REG) and energy consumption and regulatory quality (EN*REG) in Eq. (4) to determine whether regulatory quality can moderate environmental pollution in Africa via urbanisation and energy use channels.

$$ENV_{it} = \alpha_0 + \alpha_1 Y_{it} + \alpha_2 Y_{it}^2 + \alpha_3 EN_{it} + \alpha_4 URB_{it} + \alpha_5 (EN * REG)_{it} + \alpha_6 (URB * REG)_{it} + \alpha_7 POP_{it} + \alpha_8 TR_{it} + \alpha_9 FDI_{it} + \alpha_{10} CAP_{it} + \mu_{it}$$

(4)

$\alpha_1 - \alpha_9$ represent the parameter estimates, whereas the other indicators and parameters in Eq. (4) remain the same.

Therefore, to now estimate the models, the study utilises the dynamic heterogeneous panel regression (DHPR) method suggested by Pesaran et al. (1999). The methodology is built on the framework of panel-ARDL and is appropriate for a heterogeneous panel like ours. Aside from this, the DHPR is advantageous for analysing panels with large N and T, unlike the system generalised moment method (Sys-GMM). Also, it is not sensitive to the order of integration as it is appropriate for series with mixed integrating order, say I(0) and I(1) (Pesaran et al., 1999; Destek & Sarkodie, 2019; Mesagan et al., 2020). In this respect, the main estimators of the DHPR suggested by Pesaran et al. (1990) include the pooled mean group (PMG), dynamic fixed effect (DFE), and mean group (MG). However, the reliability of the estimators depends on whether there is cross-sectional independence among the panel. Otherwise, the estimators (i.e. PMG, DFE, and MG) produce inconsistent estimates. Therefore, when cross-sectional dependence exists among the panel, the augmented mean group (AMG) proposed by Eberhardt and Teal (2010) and the common correlated effect mean group (CCEMG) suggested by Pesaran (2006) become adequate to analyse heterogeneous panel series. Both the AMG and CCEMG inherently accommodate cross-sectional dependence (CD). However, the way the AMG and CCEMG take care of CD varies. For instance, the CCEMG takes the cross-sectional mean of the regressors and the regressand and then includes them on the right-hand side of the model. Whereas the AMG corrects for CD through the common dynamic process, and we depict this process with Eq. (5) and (6) as;

$$\text{StepI:}\ \Delta z_{it} = \sum_{j=1}^{p-1} r_{ij}^{*} \Delta z_{i,t-j} + \sum_{j=0}^{q-1} v_{ij}^{*} x_{i,t-j} + \sum_{t=2}^{T} ct \Delta D_t + \mu_{it} \Rightarrow \hat{c}t \equiv \hat{\mu}_{it} \qquad (5)$$

$$\text{StepII:}\ \Delta z_{it} = w_i + \sum_{j=1}^{p-1} r_{ij}^{*} \Delta z_{i,t-j} + \sum_{j=0}^{q-1} v_{ij}^{*} x_{i,t-j} + c_i t + d_i \hat{\mu}_t + \hat{\mu}_{it} \quad (6)$$

Eq. (5) and (6) represent the two steps of the AMG common dynamic process. Δ is the first difference I(1) factor, w_i is the constant term and μ_i captures the stochastic disturbance factor. Step (I) estimate the pooled OLS estimate at I(1) with $T-1$ year dummies in I(1) to derive the I(1) estimate $\hat{\mu}_{it}$ and step (II) re-estimation of the OLS panel regression after augmenting for $\hat{\mu}_{it}$ in the model. Additionally, x_{it} represent the sets of independent variables while z_{it-j} the regressand appears as regressors. $i = 1, 2, .., N$ is the cross-section, $t = 1, 2, .., T$ is time factor while r_{ij} and v_{ij} are the slopes of regression, p and q are lag indicators. Through this process, the AMG adjust for CD.

Concerning the data for analysis, we source data ranging from 1996 to 2020 for 33 African[1] countries for the World Bank Database (2022). We now describe the variables and indicators of measurement on Table 1.

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[1] List of countries

Angola, Algeria, Benin, Botswana, Cameroon, Congo Democratic Republic, Chad, Cote d'Ivoire, Congo Republic, Egypt, Gabon, Ethiopia, Ghana, Gambia, Guinea Bissau, Guinea, Libya, Mauritius, Mauritania, Mali, Morocco, Mozambique, Rwanda, Namibia, Nigeria, Niger, Senegal, South Africa, Tanzania, Tunisia, Togo, Zambia, Zimbabwe

Table 1: Variable Identification and Measurement Description

Variable Identification	Measurement	Reference	Source
Environmental pollution (***ENV***)	Measured with CO2 emission per capita in million tons (MT)	Mesagan et al. (2021), Maduka et al. (2021)	WDI, 2022
Income level (***Y)***	Captured with GDP per capita	Mesagan et al. 2021, Mesagan and Olunkwa (2022)	WDI, 2022
Income Squared (Y^2)	Calculated from Y		Derived
Energy consumption (***EN)***	Measured with energy use per capita	Dogan and Seker 2016, Mesagan et al. 2021	WDI, 2022
Urbanisation (***URB)***	Measured with urban population annual growth rate	Dimnwobi et al. 2021	WDI, 2022
Regulation (***REG)***	Captured with the estimate of regulatory quality	Mesagan and Olunkwa (2022)	WGI, 2022
Energy consumption-regulation ***(EN*REG)***	It is the interaction of energy consumption and regulatory quality	-	Derived
Urbanisation-regulation ***(URB*REG)***	It is the interplay of urbanisation and regulation	-	Derived
Population (***POP)***	Captured with the population growth rate	Dimnwobi et al. (2021)	WDI, 2022
Trade openness (***TR)***	It is captured with the degree of trade openness with other nations as a % of trade	Mesagan et al. (2021)	WDI, 2022
Foreign direct investment (***FDI)***	It is measured with net inflows of FDI in the ratio of GDP	Mesagan et al. 2021, Mesagan and Olunkwa (2022)	WDI, 2022
Physical capital (***CAP)***	Measured with the gross fixed capital formation in % of GDP	Maduka et al. (2021)	WDI, 2022

Note: WDI means World Development Indicators, and WGI indicates World Governance Indicators.

Sources: Authors compilation (2022)

4. Empirical Results

4.1 Preliminary Examination

We present the cross-sectional dependence (CD) evidence in Table 2 to ascertain whether CD exist among the panel. We employ the Pesaran CD and Freidman diagnostic to check CD.

Table 2: Cross-Sectional Dependence (CD) Diagnostic

H0: Cross-sectional dependence exist						
	I		II		III	
Test	**Stat.**	**Prob.**	**Stat.**	**Prob.**	**Stat.**	**Prob.**
Pesaran CD	38.553***	0.0000	39.022***	0.0000	39.892	0.0000
Friedman CD	225.63***	0.0000	234.64***	0.0000	231.08	0.0000

*Note: *** represents 1% critical value*

Sources: Authors compilation (2022)

In Table 2, the Pesaran CD and Friedman's evidence suggest a solid cross-sectional dependence in the panel for all our models at 1% significance. This implies that we accept H_0 and conclude that CD exists among the series. The CD evidence suggests that African countries share a common pollution problem. Since pollution is transboundary, any abatement policy implemented in any country will affect other African nations. With the presence of CD, we proceed to estimate the 2nd generation panel unit root (PURT) suggested by Pesaran (2007) because the usual 1st generation is inappropriate when CD exists. We present the 2nd generation PURT in Table 3.

Table 3: 2nd Generation PURT

Variables	**H0:** **`No Stationarity`**					**Stationarity**
	CIPS @ I(0)	**CIPS @ I(1)**	**0.10**	**0.05**	**0.01**	**Status**
ENV	-1.039	-3.556***	-2.73	-2.86	-3.1	I(1)
Y	-1.494	-2.888**	-2.73	-2.86	-3.1	I(1)
Y^2	-1.348	-2.799*	-2.73	-2.86	-3.1	I(1)
EN	-2.792*	-2.125	-2.73	-2.86	-3.1	I(0)
URB	-2.268	-5.119***	-2.73	-2.86	-3.1	I(1)
REG	-4.221***	-5.669***	-2.73	-2.86	-3.1	I(0)
(EN*REG)	-4.411***	6.805***	-2.73	-2.86	-3.1	I(0)
(URB*REG)	-4.503***	-6.325***	-2.73	-2.86	-3.1	I(0)
POP	-2.347	-4.698***	-2.73	-2.86	-3.1	I(1)
TR	-3.204***	-5.515***	-2.73	-2.86	-3.1	I(0)
FDI	-0.658	-2.911**	-2.73	-2.86	-3.1	I(1)
CAP	-1.721	-3.811**	-2.73	-2.86	-3.1	I(1)

*Note: I(0) and I(1) represent stationarity status at levels and first order of integration, *, **, and *** denotes 10%, 5%, and 1% critical value*

Sources: Authors compilation (2022)

Table 3 shows environmental pollution (ENV), income (Y) and the squared (Y^2), urbanisation (URB), population (POP), foreign direct investment (FDI), and physical capital are stationary at I(1). Whereas the rest variables are stationary at I(0). It signifies that all the panel series are stationary. Hence we reject H_0. The stationarity condition of the panel data necessitates a panel cointegration test. Since there is CD, we now test for cointegration in the panel using the Westerlund cointegration. We present Westerlund's cointegration result for models I-III in Table 4.

Table 4: Westerlund Panel Cointegration

H0: No cointegration			
Model (1)			
Statistic	**Value**	**Z-value**	**Robust P-value**
Gt***	0.440	6.522	0.000
Ga***	0.301	3.635	0.000
Pt***	1.072	4.656	0.000
Pa***	4.779	3.975	0.000
Model (2)			
Gt***	0.490	6.348	0.000
Ga***	1.528	4.325	0.000
Pt***	0.883	4.653	0.000
Pa***	0.830	2.668	0.000
ModeL (3)			
Gt***	0.512	6.237	0.000
Ga***	1.672	4.325	0.000
Pt***	0.974	4.763	0.000
Pa***	0.834	2.752	0.000

*Note *** indicates 1% critical value*

Sources: Authors compilation (2022)

Table 4 reveals the presence of cointegration among the panel series for all the models. This means a strong long-run association exists among the series in models (1-3. Finally, the study presents the correction matrix in Table 5 to ascertain the degree of association between the variables. This ensures that we do not include strongly correlated variables in a single model likely to cause spurious regression.

Table 5: Correlation Matrix

	ENV	*Y*	*Y^2*	*EN*	*URB*	*REG*	*(EN*REG)*	*(URB*REG)*	*POP*	*TR*	*FDI*	*CAP*
ENV	1.00											
Y	0.75	1.00										
Y^2	0.70	0.67	1.00									
EN	0.70	0.45	0.47	1.00								
URB	0.55	0.57	0.71	0.43	1.00							
REG	0.12	0.21	0.19	0.09	0.002	1.00						
(EN*REG)	-0.27	-0.14	-0.15	-0.46	-0.24	0.45	1.00					
(URB*REG)	-0.11	-0.03	-0.10	-0.06	-0.38	0.55	0.58	1.00				
POP	0.47	-0.52	-0.59	-0.28	-0.31	-0.17	0.07	-0.06	1.00			
TR	0.39	0.59	0.56	0.15	0.41	0.08	-0.12	-0.11	-0.39	1.00		
FDI	0.02	0.12	0.05	-0.06	0.10	-0.00	0.02	-0.04	0.02	0.35	1.00	
CAP	0.27	0.03	0.15	-0.04	0.14	0.04	0.08	-0.01	0.11	0.20	0.27	1.00

Sources: Authors compilation (2022)

The correlation matrix in Table 5 shows a moderate correlation between the series since we do not have a more than 80% coefficient. We now conclude that our series are not strongly related, and thus we are less likely to encounter multicollinearity problems. Therefore, we proceed to estimate the panel regression.

4.2 Panel Regression

Since Table 2 suggests that African countries are cross-sectionally dependent, the PMG, DFE, and MG estimators become unreliable for generating consistent estimates to guide the prescription of a pollution control policy for Africa. Hence, the AMG and CCEMG estimators become more appropriate to estimate the panel regression because they accommodate CD. Therefore, we present the AMG results in Table 6, and the CCEMG estimates in Table 7 to check the robustness of the AMG since both adjust for CD.

Table 6: Augmented Mean Group Estimate

Explanatory Var.	**Dependent Var. ΔENV**		
	Model(1)	**Model(2)**	**Model (3)**
Y	0.0049*	0.0056*	0.0055**
	(0.0025)	(0.0029)	(0.0027)
Y2	-9.7452**	-14.695***	-14.928***
	(4.5497)	(5.3328)	(5.3016)
EN	0.0005***	0.0005***	0.0008***
	(0.0001)	(0.0001)	(0.0002)
URB	0.2571	0.1298	0.0006
	(0.2043)	(0.2020)	(0.1342)
REG	-	-0.0622	-
		(0.0470)	
(EN*REG)	-	-	-0.0006***
			(0.0001)
(URB*REG)	-	-	-0.0002
			(0.0073)
POP	0.3002**	0.1501***	0.1724***
	(0.1416)	(0.0471)	(0.0157)
TR	0.0020	0.0024	0.0027*
	(0.0019)	(0.0021)	(0.0015)
FDI	0.0137***	0.0134***	-0.0173***
	(0.0047)	(0.0041)	(0.0067)
CAP	0.0115**	0.0099*	0.0073**
	(0.0049)	(0.0055)	(0.0025)
Trend	0.0465	0.0995	0.0954**
	(0.0976)	(0.0811)	(0.0216)
Intercept	87.366**	93.801**	69.459*
	(41.570)	(43.520)	(37.820)

*Note: Lag length one (1) is selected based on the decision of Akaike Information Criteria (AIC), *, **, and *** denotes 10%, 5%, and 1% critical value, and values in ( ) is the standard error of the regression parameters.*
Sources: Authors compilation (2022).

Table 5 reveals that energy consumption and urbanisation positively impact environmental pollution across models (1-3). As energy use changes by a unit, environmental degradation in Africa rises by 0.0005, 0.0005, and 0.0008 units, assuming that other regressors in the model are constant. Similarly, for any unit change in urbanisation, pollution in Africa rises by 0.2571, 0.1298, and 0.0006 units keeping the rest variables constant. Energy consumption is strongly significant across the models at 1% critical value, whereas urbanisation is insignificant at any of the critical value thresholds (1%, 5% and 10%). The meaning of the evidence is that energy consumption increases pollution significantly, whereas urbanisation increases environmental pollution insignificantly. Moreover, the positive but insignificant impact of urbanisation on environmental pollution in Africa denotes that urbanisation has the tendency to worsen pollution since it exacts a positive effect on the pollution variable.

However, to ascertain the mediating role of regulation on pollution abatement via energy use and urbanisation channel, the result shows that regulatory quality negatively affects pollution. But, it is insignificant. Therefore, it denotes that regulatory quality can control pollution in Africa, but the impact is weak. Moreover, holding other variables in the model (2) constant, a percentage change in regulatory quality in Africa reduces environmental pollution by about 6.2%.

Regarding the moderating role of regulation, the evidence shows that the interaction of energy consumption and regulation has a negative but significant impact on pollution. As the interaction changes by a unit, pollution reduces in Africa by 0.0006 units at 1% critical value. In the same vein, urbanisation and regulation interaction exact a negative but insignificant impact on pollution, and if it changes by a unit, environmental degradation declines by at least 0.0002 units. The finding implies that energy consumption and regulatory quality interaction substantially lowers pollution because it has a negative sign and is significant. In contrast, urbanisation and regulatory quality interaction have the tendency to reduce environmental pollution because the impact of the interaction has a negative sign but is insignificant at any of the critical values (1%, 5% and 10%). We provide a detailed discussion and implications of the findings in section 4.3

Lastly, checking the conformity of our estimates with the EKC preposition, Table 6 shows that EKC assumptions hold for Africa since we obtain a positive value of Y and a negative value of Y across the three models. The implication is that pollution increase accompanies an increase in income at the initial growth stage, but as income increases, pollution reduces.

Table 7: Robustness Check using the Common Correlated Effect Mean Group (CCEMG)

Explanatory Var.	**Dependent Var. ΔENV**		
	Model(1)	**Model(2)**	**Model(3)**
Y	0.0010	-0.0014	0.0001
	(0.0014)	(0.0021)	(0.0029)
Y2	-0.9223	-1.1313	-8.5545
	(2.5631)	(4.3532)	(6.5355)
EN	0.0003***	0.0003***	0.0007**
	(0.0001)	(0.0001)	(0.0004)
URB	0.7716	0.1013	0.4378
	(0.7100)	(0.5632)	(0.3881)
REG		0.1566	-
		(0.1536)	
EN*REG		-	-0.0003
			(0.0002)
URB*REG		-	-0.0007
			(0.0076)
POP	0.3527	0.3202	0.6157*
	(0.1235)	(0.1289)	(0.3476)
TR	-0.0030	-0.0025	-0.0010
	(0.0027)	(0.0027)	(0.0026)
FDI	-0.0088*	-0.0090	-0.0037
	(0.0046)	(0.0044)	(0.0064)
CAP	0.0094	0.0083	0.0049
	(0.0069)	(0.0053)	(0.0043)
AV_ENV	0.9883***	0.9743	0.9832
	(0.2537)	(0.2478)	(0.2466)
AV_Y	0.0003	0.0005	0.0007
	(0.00050	(0.0004)	(0.0007)
AV_Y2	-2.4530	-4.5069	-5.3191
	(2.2619)	(2.8678)	(3.5077)
AV_EN	-0.0004***	-0.0004*	0.0003
	(0.0001)	(0.0002)	(0.0005)
AV_URB	0.1818	-0.1215	0.1002
	(0.5451)	(1.1214)	(1.3542)
AV_REG	-	0.0075	-
		(0.1286)	
AV_ (EN*REG)	-	-	0.0008
			(0.0006)
AV_ (URB*REG)	-	-	-0.0117
			(0.0085)
AV_POP	-0.3441	-0.1175	-0.2963
	(0.3989)	(0.2411)	(0.2707)
AV_TR	0.0021	0.0049	0.0017
	(0.0014)	(0.0029)	(0.0045)
AV_FDI	0.0033	-0.0066	0.0081
	(0.0107)	(0.0091)	(0.0202)
AV_CAP	-0.0106	-0.0046	-0.0149
	(0.0097)	(0.0087)	(0.0103)
Trend	0.3260	0.1750	-0.2110
	(0.3323)	(0.4739)	(0.5723)
Intercept	44.169	46.183	61.592
	(42.612)	(66.744)	(68.899)

*Note: Lag length one (1) is selected based on the decision of Akaike Information Criteria (AIC), *, **, and *** denotes 10%, 5%, and 1% critical value, and values in ( ) is the standard error of the regression parameters.*

Sources: Authors compilation (2022).

We present the CCEMG result to check the robustness of the AMG estimates since both estimators accommodate CD, but the approach to their adjustment varies, as discussed earlier. Therefore, Table 7 shows that energy consumption and urbanisation exact a positive relationship with environmental pollution. This indicates that energy consumption and the pace of urbanisation increase environmental pollution. This evidence is consistent with the AMG estimates. Also, introducing regulatory quality into the model regulation negatively affects pollution. It implies that regulation improves the environment and lowers pollution. The evidence is also the same as the AMG result. Lastly, energy use and regulatory quality interaction and urbanisation and regulatory quality interaction affect pollution negatively. It denotes that energy use regulation and urbanisation regulation improves the environment by abating pollution. The result is somewhat similar to the AMG estimates we present in Table 6.

4.3 Discussion of Findings

The empirical findings of this study are quite revealing. First, we discover that African countries are cross-sectionally dependent. This necessitates the adoption of the AMG and CCEMG frameworks to analyse the data for Africa. Interestingly, both estimates produce somewhat similar results. Hence, we use the CCEMG for robustness check. Therefore, concerning the impact of urbanisation and energy consumption on pollution, evidence reveals that energy use has a positive and significant effect on Africa's pollution across models (1-3). This result is unsurprising because fossil fuel is the primary energy source for households-lighting and cooking, industrialisation and transportation in the region. Thus, energy consumption is rising because Africa's population, urbanisation and industrial activities are rising, thus causing energy consumption to deter environmental quality. The evidence is in agreement with the findings of Bastola & Sapkota (2015), Behera & Dash (2017), Solarin et al. (2018), Khan et al.(2019), Mesagan et al. (2020), and Nathaniel et al. (2020).

Furthermore, urbanisation in Africa has a positive relationship with environmental pollution based on the evidence. But the impact of the relationship is insignificant at any of the critical thresholds. The positive effect of urbanisation on environmental pollution indicates that as the urbanisation rate expands, pollution in Africa also rises, even though it is insignificant. This is revealing because Africa has one of the fastest urban growth rate globally, with an annual urban growth rate of 3.58%, and with a projection that the urban cities will be home to additional 950 million people by 2050

(OECD, 2020; United Nations Economic Commission for Africa (UNECA), 2021). This urbanisation pace has the tendency to pose environmental challenges because urbanisation hastens the depletion of forests to provide housing and employment for the growing urban population. Also, urban growth increases energy consumption intensity in the urban area via the transport industries and heavy energy-dependent firms. All these activities thrive due to urban growth, thereby threatening environmental quality. This evidence aligns with studies like Effiong (2017), Adams &Klobodu (2017), Salahuddin et al. (2018), and Mignamiss & Djeufack (2021).

We ascertain the mediating role of regulatory quality on pollution control via energy consumption and urbanisation channel. The evidence shows that regulation reduces environmental degradation. However, it is not significant. This implies that strong regulation can mitigate pollution, but it is insignificant because regulatory quality is generally weak in Africa. It now infers that if African countries step up regulatory efforts, it can substantially reduce environmental decay. The evidence is similar to Al-Mulali & Ozturk (2015), Adams &Klobodu (2017), and Mesagan & Olunkwa (2022). Moreso, since regulatory quality has the potential to mitigate pollution, we now separately interact energy consumption and regulatory quality and urbanisation and regulatory quality to ascertain its moderating effect on pollution. The evidence shows that both moderations negatively affect Africa's pollution because the coefficients are negative. It implies that both moderations cause pollution to reduce in Africa, but (EN*REG) is significant at 1% critical value while (URB*REG) is not significant. The meaning of the negative signs is that energy consumption-regulation and urbanisation-regulation interaction can lower pollution in Africa. Strikingly, Table 5 shows that both moderations (EN*REG) and (URB*REG) negatively correlate with environmental pollution (ENV), thereby supporting the AMG results. Therefore, since both moderations reduce pollution, it shows that sound regulation of the energy sector and housing development regarding urban sprawl can help reduce the negative impact of energy consumption and urban expansion on Africa's environment, thereby achieving sustainable energy and smart cities necessary for carbon neutrality by 2050. However, this energy use-regulation evidence is in tandem with Mesagan and Olunkwa (2022) findings for Africa. The implication is that African countries can step up the implementation of quality regulations through energy use and urbanisation channels to control pollution in the continent.

5. Conclusion and Policy Prescription

We assess the role of regulatory quality on environmental pollution through urbanisation and energy consumption channel in Africa between 1996 and 2020. The study considers cross-sectional dependence (CD) and adopts the AMG and CCEMG approach based on a dynamic heterogeneous panel regression framework to analyse 33 African economies. However, the CCEMG is to check the robustness of the AMG estimator since both techniques adjust for CD, and both results are similar. The empirical result shows that the urbanisation rate in Africa increases pollution. Energy consumption has a positive impact on environmental degradation. As regulatory quality enters into the model, it has a negative impact on pollution in Africa. This implies that regulatory quality can mediate carbon emission control through urbanisation and energy consumption. The interaction of urbanisation and regulatory quality lowers pollution, and energy consumption and regulation interaction improve the environment. Following the empirical revelation of the study, we suggest that African countries strategically roll out smart urban development policies to lower the impact of urban spread on climate change. Also, the region should intensify its campaign for energy efficiency practices in African countries to offset the negative impact of energy on the environment. Lastly, since the interactions (i.e., URB*REG and EN*REG) lower pollution, it implies that Africa's regulatory framework can potentially moderate environmental deterioration through proper urbanisation planning and sustainable energy policy in the region. Moreso, the outlined plans and policies should be effectively implemented for optimum results. Therefore, the study suggests that African countries should strengthen their environmental regulations through renewed collective efforts to reduce environmental hazards and substantially guarantee sustainability. Furthermore, the current study can be replicated in the African continent's various sub-regions and countries to unravel each country's peculiarity. Similarly, a comparative study can be undertaken for Africa and other regions of the world to know how effective the regulatory quality of the various regions are.

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