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URBANIZATION, FINANCIAL DEVELOPMENT, AND ENVIRONMENTAL QUALITY IN SUB-SAHARAN AFRICA: AN EMPIRICAL ANALYSIS USING THE STIRPAT MODEL

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Abstract:

The objective of this paper is to determine the effects of urbanization and financial development on environmental quality while simultaneously exploring the validation test of the Environmental Kuznets Curve (EKC) hypothesis. Our analysis is based on unbalanced panel data covering 21 Sub-Saharan African countries and covering the period 1990-2019. The methodological approach used, relied first on some preliminary tests (notably the dependence test between individuals in the sample, the panel unit root test, and the cointegration test), then on the PMG/ARDL method[1] for parameter estimation, and finally, on the Granger causality test. The results show that, primary energy consumption, economic growth, urbanization, and trade openness have a positive and significant influence on environmental quality in the long term. The EKC hypothesis is not validated. Based on the analysis and interpretation of the results obtained, we recommended among other things that, environmental conservation be considered in the development of trade policies, as well as the granting of financing to projects that promote green investments, due to Sub-Saharan Africa's rapid urbanization, the local governments should integrate this factor into their development plans, and also, define urban policies that can be transformed into local initiatives aimed at combating environmental degradation.

Keywords: urbanization, financial development, environmental quality, EKC, PMG/ARDL method

JEL Classification: J19; O18; O13; C23

1. Introduction

Since the industrial revolution, the pursuit of economic growth has resulted in the rapid development of mechanisation in agriculture, manufacturing, transport and services. These

[1] Pooled Mean Group/AutoRegressive Distributed Lag

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activities consume fossil fuels and therefore contribute to global warming and environmental degradation. The release of the Meadows report in the 1970s, with the slogan "Stop Growth", drew the attention of humanity to the consequences of unbridled economic growth on the environment.

Theoretically, the study of the link between economic growth and the environment can be traced back to the pioneering work of Shafik and Bandyopadhyay (1992), Panayotou (1993) and Grossman and Krueger (1995), who have particularly explored the EKC hypothesis. Indeed, this hypothesis postulates that CO_2 emissions and economic development grow simultaneously up to a certain threshold, after which these emissions decrease as economic development increases, Since the mid-1990s, this hypothesis has been the subject of several empirical tests (Andreoni and Levinson, 2001; Chimeli and Braden, 2009; Di Vita, 2008; Kijima et al., 2010; Lieb, 2002; McConnell, 1997; Prieur, 2009). Empirically, several studies have investigated the link between economic growth and CO_2 emissions in relation to various explanatory variables (among others, democracy, human capital, renewable and primary energy consumption, corruption, trade openness,…). The present work builds on this momentum and highlights urbanization and financial development.

Urbanization in recent times, is considered as one of the important factors of economic development and may subsequently have consequences on the environment. It is growing rapidly and heterogeneously (across continents, regions, countries, communities) over the years. The United Nations report of 2017 already revealed that approximately 54% of the world's population lives in urban areas, a rate projected to increase to 66% by 2050. Africa and Asia have higher rates than other regions of the world. Its implication for environmental quality remains mixed. While some studies have shown that urbanization intensifies carbon emissions (Al-Mulali et al., 2013; Li et al., 2012; Pata, 2018; Poumanyvong and Kaneko, 2010; Ren et al., 2015), others conclude that urbanization has no effect on CO_2 emissions (Du et al., 2012; Pata et al., 2018; Sadorsky, 2014; Sharif, 2011) and some have found an inverted U-shaped relationship between them (He et al., 2017; Lin and Zhu, 2017; Wang et al., 2015b; Zhang et al., 2017). Urbanization goes hand in hand with increased energy consumption, especially in the transport sector, the destruction of primary forests (for housing and farming), increased trade and the multiplicity of financial institutions.

Financial development plays a major role in the energy use and economic development of both developed and underdeveloped states. Many countries around the world have abundant energy resources and produce beyond their required level. Others, on the other hand, face reduced energy levels and depend on primary energy sources. Similarly, some countries have well-developed and well-structured financial institutions. However, their effects on the environment are equally ambiguous. Financial development can promote and stimulate carbon emissions by financing various energy projects (Sher et al., 2020).

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The objective of this paper is to investigate the influence of urbanization and financial development on environmental quality in sub-Saharan Africa. Several studies have been carried out in this respect, but very few in the African context. This work is therefore original in that it follows on from previous studies but applies a different methodology. Furthermore, it verifies the existence of a potential non-linear relationship between urbanization, financial development and environmental quality.

The present study contributes to the existing literature by examining the effects of urbanization and financial development on environmental quality in Sub-Saharan Africa and by assessing the causality between the variables considered. Our study differs from previous studies in the introduction of financial development into the STIRPAT model. In addition, the non-linearity of urbanization and financial development is tested in the Environmental Kuznets Curve (EKC) model.

After this introductory section, the remaining portion of the paper is organized as follows: the second section deals with the empirical literature, section three clearly outlines the methodology of the study, the empirical results and discussions, and the conclusion and policy implications will fill sections four and five respectively.

2. Literature Review

This section presents the empirical literature on the link between urbanization, financial development and environmental quality. This link can be presented under three headings.

2.1. Urbanization and Environmental Quality

Urbanization as a demographic indicator, describes the concentration of population in urban areas following economic transformation and social modernization. A careful analysis of the link between urbanization and environmental quality is imperative for the design of appropriate policies for sustainable development and climate change, given the rapid growth of urbanization in Africa since the 1990s. This growth leads to heavy use of natural resources and expansion of economic activities and, consequently, greater environmental pollution. This section, therefore, looks at the relationship between urbanization and environmental quality.

The starting point for the theoretical review is the theory of ecological modernization, which shows the transformational process of urbanization. As societies evolve (from low to intermediate levels of development), economic growth takes precedence over environmental sustainability. When societies reach higher levels of development, environmental damage becomes more significant, and societies look for ways to achieve environmental sustainability. The negative effects of growth on the environment can be lessened by technological innovation, urbanization and the transition from a manufacturing economy to a service economy (Gouldson and Murphy, 1997; Mol and Spaargaren, 2000).

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The literature contains a range of studies that investigate the nature of the link between urbanization and environmental quality, using a variety of econometric approaches, data types and sources, study periods and geographical contexts. For Li and Lin (2015), the influence of urbanization on carbon dioxide emissions depends on the level of economic development, with high and middle-income countries experiencing adverse effects and low-income countries experiencing mixed effects. Cole and Neumayer (2004) and Sharma (2011) conclude that urbanization reduces carbon dioxide emissions. This result is also obtained by Shahbaz et al. (2014) for UAE countries; Sadorsky (2014) for 16 emerging economies; Adusah-Poku (2016) for Sub-Saharan Africa where he applies the PMG method. Using an ARDL model to study the impacts of population density, fossil fuels, and economic development on carbon emissions in the context of Pakistan, India, and Bangladesh (1971-2014), Ali and al. (2020) find that population density has a positive impact on CO_2 emissions. The same result is obtained by Khan and al. (2020) for the population factor alone in the context of Pakistan (1990-2015). Mansoor and Sultana (2018) find that it is demographic dynamism and energy consumption that boost CO_2 emissions; while economic growth, has a negative effect. Using a STIRPAT model on panel data of different sizes, York and al. (2003a), Martinez-Zarzoso and Maruotti (2011), Poumanyvong and Kaneko (2010) find that a high level of urbanization leads to higher CO_2 emissions. The same result is obtained by Wang and al. (2017) for the eastern region of China, Asongu and al. (2020) for 13 sub-Saharan African countries between 1980 and 2014, and Mignamissi and Djeufack (2021) for 48 African states.

On another level, several studies have found contrasting results on the impact of population on emissions of CO_2, Begum and al. (2015) find an insignificant effect in the context of Malaysia. Identical results obtained by Rahman (2017) for 11 most populous Asian nations, Sulaiman and Abdul-Rahim (2018) for Nigeria, Mosikari and Eita (2020) for 29 African economies.

Although, most studies suggest that the urbanization-pollution relationship is linear, the lack of clear evidence has led researchers to consider the possibility of a non-linear relationship. For instance, Ehrhardt-Martinez and al. (2002) found evidence that relationship between urbanization and deforestation rates in developing nations exhibit an inverted U-shaped relationship using the Environmental Kuznets curve (EKC) model. Other studies have employed non and semi-parametric regression as a more flexible estimation framework to circumvent possible functional form misspecification bias in determining the true shape of the urbanization-pollution relationship.

For instance, Zhu and al. (2012) find little evidence in support of the inverted U-shaped relationship for 20 emerging countries. Also, Wang and al. (2015) confirm these findings for the urbanization-Sulphur oxides (SO_2) emissions nexus in China. Wang and al. (2016) and

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Xu and Lin (2015) found an inverted U-shaped relationship between urbanization and CO_2 emissions for OECD countries and China respectively. Examining the urbanization-pollution nexus in Africa are nascent. Onoja and al. (2014) found a positive but insignificant effect of urbanization on CO_2 emissions. Adusah-Poku (2016) using dynamic heterogeneous panel data models found that urbanization contributes positively to CO_2 emissions in Sub-Saharan Africa both in the short and long run.

2.2. Financial Development and Environmental Quality

From an empirical point of view, several works have attempted to study the impact of financial development on carbon emissions. On a panel of 40 European countries (1985-2014), Sy and al. (2016) detected the existence of a hallo hypothesis between financial development and carbon emissions. Applying a VECM on time series in the context of Bangladesh (1985-2015), Alom and al. (2017) found that financial development has a positive impact on carbon emissions. The same result is obtained by Al-Mulali and al. (2015) in the context of 129 countries classified by income level, Tamazian and Rao (2010) in states with strong institutions, Frankel and Romer (1999), Zhan and Lin (2011). To Zhang (2011), increased financial development increases carbon emissions. Al-Mulali and Sab (2012a) find that energy consumption stimulated by financial development is the cause of increased carbon emissions in the context of sub-Saharan African states. The same result is obtained by many others namely, Boutabba (2014) in the case of India, Sadorsky (2011) in Central and Eastern Europe, Komal and Abbas (2015) for Pakistan, in the context of Turkey, Katircioğlu, and Taspinar (2017) and Cetin et al. (2018), Tsaurai (2019) for 12 West African economies.

In contrast to those mentioned above, other studies have found a negative association, Jalil and Feridun (2011) provided evidence that financial development reduces environmental pollution in China. The same result is obtained by Tamazian and al. (2009), Shahbaz and al. (2013a) in the context of Indonesia, Saahuddin and al. (2015) for the GCC states, Dogan and Seker (2016) for 23 countries, in the context of Pakistan, Abbasi and Riaz (2016) and Shahbaz et al. (2016), Nasreen and al. (2017) in South Asian economies, Saidi and Mbarek (2017) for 19 emerging economies, Zafar and al. (2019) in the context of 27 OECD states.

Besides these two groups of works, there are those that find non-significant results between financial development and carbon emissions. Ozturk and Acaravci (2010) in the context of Turkey found that financial development has no significant impact on greenhouse gas emissions. Dogan and Turkekul (2016) obtained a similar result in the context of the United States, Salahhuddin et al. (2018) for Kuwait, Lu (2018) for 12 Asian economies, Charfeddine and Kahia (2019) for 24 MENA states.

Still, within this framework of the literature on environmental quality, we note other influencing factors, in particular, economic growth, the consumption of renewable and/or fossil fuels, and trade openness. Indeed, authors such as Keppler and Mansanet (2010),

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Narayan and Narayan (2010), and Pao and Tsai (2011) have indicated that economic growth and energy consumption are accompanied by environmental degradation in developed and developing countries. Copeland and Taylor (2001) address the environmental effects of a trade by econometrically testing the magnitude of the three effects (scale, composition, and technical). They find that trade liberalization increases SO_2 emissions through the scale effect, but the accompanying technical effect reduces them, so the total effect is ultimately beneficial. Estimating the effects of economic openness on income growth and water pollution in Chinese provinces (1987-1995), Dean (2002) found that trade openness has a negative impact on water quality, but mitigates it indirectly through its effect on income growth. Examining the causality between energy consumption and carbon emissions for OECD and MENA countries, Dinda (2004) found that there is a causal relationship between carbon emissions and gross domestic product per capita in OECD countries, but the relationship is not the same in non-OECD countries. Working on financial market variables, Sadorsky (2010), found that financial development increases energy consumption. The positive link between economic activities and carbon emissions in developed countries is the result of research obtained by Muhammad (2019). Saidi and Hammami (2015a, b) found in Latin America, North Asia, Europe, and the Caribbean that there is a bidirectional relationship between energy consumption and output per capita. In a study on the relationship between carbon emissions, energy consumption, and economic activities in China and specifically in Shanghai, Yang and Lin (2016) found a bidirectional causality between real gross domestic product, carbon emissions, and energy consumption. Tiwari (2011) in the context of India found a long-term relationship between primary energy, carbon emissions, and economic development. Salahuddin and Gow (2019) found a plausible positive association between energy consumption and carbon emissions.

This overview of the literature on the link between urbanization and financial development shows that many studies have not been conducted in the context of sub-Saharan African states, and the hypothesis of testing the EKC model against various explanatory variables is still in the making.

This work is therefore important in that, firstly, it complements work in the field of environmental economics; secondly, it verifies the hypothesis of the environmental Kuznets curve (EKC) in the context of Sub-Saharan Africa by applying different methodologies; and thirdly, it verifies the existence of a potential non-linear relationship between urbanization, financial development and the quality of the environment.

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3. Methodology

This section deals in general with the empirical study. It first deals with the presentation of the data, then the theoretical framework, the specification of the models to be estimated and finally the methodological approach.

3.1. Data sources of the variables and their description

This study aims to verify whether urbanization and economic development influence environmental quality in sub-Saharan Africa. To achieve this, a panel of 21 countries[2] (Angola, Benin, Botswana, Cameroon, Democratic Republic of Congo, Congo, Ivory Coast, Gabon, Ghana, Kenya, Mauritius, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan, Tanzania, Togo, Zambia and Zimbabwe) were selected covering the period 1990-2019. The data used were all secondary in nature and were extracted from various sources including the World Bank (2020) database and the Global Carbon Project. They are presented in Table 1.

Table 1: Description, expected signs and data sources

[2] The choice of countries depended on the availability of statistical data.

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Variables	Description	Authors :	Expected signs	Sources
Endogenous variable				
eq	The environmental quality indicator is measured by the amount of CO_2 emitted by the energy sector and expressed in millions of tonnes of CO_2 equivalent ($MtCO_2e$).	Mohamed and Wajdi. 2021; Stephen and al. 2021; Muhammad and al. 2016; Yang and al. 2016		Global Carbon Project (CATI)
Exogenous variables				
$\boldsymbol{renc}$	Renewable energy consumption indicator measured by total renewable electricity consumption per capita and expressed in Kilowatt-hours.	Zakaria, 2017; Fatih and Bahar. 2015; Soheila and Ehsan, 2017; Bahman and Nigar, 2022.	$-$	WDI
$\boldsymbol{enc}$	Primary energy consumption indicator measured by kg oil equivalent per capita	Yasser and al., 2017; Hamisu and al., 2016; Sher Khan and al., 2019, 2020; Chung-Siong and Mori, 2022; Avishek,. 2021; Djepang and Tchoumo, 2020.	$\pm$	WDI
$\boldsymbol{eg}$	Indicator of economic growth. measured by real Gross Domestic Product (GDP)	Ni and Wayan, 2021; Avishek, 2021; Rahcmad and al., 2021; Jane and al., 2021; Diez and Rosa, 1997; Khaled et al., 2013;	$+$	WDI

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	per capita and expressed in constant US dollars. 2010.	Djepang and Adamou, 2021.		
$urbg$	Urbanization indicator measured by the volume of urban population	Hamisu and al., 2016; Yixi and al., 2019; Muhammad and al., 2020	±	WDI
$trade$	An indicator of trade openness measured by the percentage of foreign trade as a percentage of GDP.	Djepang and Tchoumo, 2020; Nuno and Daniel, 2020; Adedoyin and al, 2016.	±	WDI
fd	Financial development indicator measured by domestic credit extended by banks to the private sector as a percentage of GDP.	Adedoyin et al., 2016; Faiza and Khalid, 2016; Halkos and Polemis, 2017; Muhammad and al., 2016.	±	WDI

Note: WDI **= World Development Indicators.**

3.2. Theoretical framework

The theoretical framework of this study is based on the EKC and STIRPAT models. Concerning the EKC model, the analysis of a hypothetical relationship between environmental degradation and economic growth has its origins in the research of a different kind carried out by Simon Kuznets, who related measures of inequality in income distribution to economic growth. Based on data from the United States and the United Kingdom, Kuznets (1955) estimated that income inequality tended to rise at low levels of development and then fall, resulting in a relationship that was later described as "U-inverted" between income inequality and GDP per capita. A few decades later, Grossman and Krueger (1991) decided to test this hypothesis of an inverted-U curve for the relationship between environmental degradation and GDP per capita; this hypothesis was then called the Kuznets Environmental Curve (KEC). This curve can be tested by a simple regression such as:

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$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 z_{it} + \varepsilon_{it}$$

Where y is the environmental indicator for country i at time t, x is income, z is a vector of additional variables, α is a constant and ε is the error term. The parameters β estimated determine the form of the relationship between the environment and income: $\beta_2 = \beta_3 = 0$ implies a monotonic relationship between the two (positive or negative depending on the sign of β_1). If $\beta_1 > 0, \beta_2 < 0$ *and* $\beta_3 = 0$ *or* $\beta_1 = 0, \beta_2 > 0$ *and* $\beta_3 < 0$ the relationship is in the form of an "U-inverted" (EKC). Finally, if $\beta_1 > 0, \beta_2 < 0$ and $\beta_3 > 0$, the relationship is similar to an N-shape, where the first stages correspond to an EKC but the environmental situation then deteriorates for very high income levels.

The paper also uses the IPAT framework to investigate the urbanization-pollution relationship. The IPAT identity, which is a widely recognized formula for analysing the effects of human activities on the environment, is the one used to define this relationship. IPAT grew out of the Ehrlich-Holdren/Commoner debate in the early 1970s on the main driving forces behind anthropogenic environmental impacts. This model makes it possible to describe the ecological changes induced by human activities by relating environmental quality to variables such as population, tributary and technological level. This model is expressed by the following equation:

$$I = P.A.T$$

Where I is the variable measuring environmental impact; P represents the size of the population (density) living in the urban environment; A is the variable measuring human economic activity (production and consumption); and T represents the technological level per unit of consumption and production. This model has been improved by Dietz and Rosa (1997) and York and al (2003). The IPAT model has been criticized for being a mathematical identity model (accounting identity) and therefore cannot be estimated, nor can it be used to test hypotheses. Consequently, Dietz and Rosa (1997) improved the model to produce a stochastic and flexible version called STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology), which can be used to analyse the environmental effects of macro-economic variables. The equation can be translated as follows

$$I_i = aP_i^b A_i^c T_i^d \varepsilon_i$$

The variables I, P, T and A remain the same as in the IPAT model. But a, b, c and d represent the model parameters. ε_i is the error term; i denotes the observation units.

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3.3. Empirical Models

A series of empirical studies have been carried out to illustrate the impact of urbanization and financial development on the quality of the environment, and sometimes vice versa. However, these studies do not use the same econometric approaches, data or framework. They are based on the EKC (Kuznets Environmental Curve) hypothesis, the gravity model, the STIRPAT approach (Stochastic Impacts by Regression on Population, Affluence and Technology) for some and others.

The theoretical models used in this section are based on the STIRPAT approach or the Kaya (1990) equation[3] , and the EKC hypothesis. They exploit the functional forms of the work of Soheila and Ehsan (2017), Djepang and Tchoumo (2020) and Olatunji and Asongu (2021). In general, in this study, the functional form is as follows:

$$\boldsymbol{eq = f(renc, enc, eg, urbg, fd, trade)} \qquad (\mathbf{1})$$

The equation $(\mathbf{1})$ is linearised to capture the stochastic properties of the STIRPAT and EKC models which are as follows:

$$\begin{aligned}\boldsymbol{lneq_{i,t}} &= \boldsymbol{\alpha_0 + \alpha_1 lnrenc_{i,t} + \alpha_2 lnenc_{i,t} + \alpha_3 lneg_{i,t} + \alpha_4 lnurbg_{i,t} + \alpha_5 lnfd_{i,t}} \\ &\quad \boldsymbol{+ \alpha_6 lntrade_{i,t} + \tau_{i,t}} \qquad (\mathbf{2})\end{aligned}$$

$$\begin{aligned}\boldsymbol{lneq_{i,t}} &= \boldsymbol{\delta_0 + \delta_1 lneg_{i,t} + \delta_2 lneg^2_{i,t} + \delta_3 lnurbg_{i,t} + \delta_4 lnfd_{i,t}} \\ &\quad \boldsymbol{+ \delta_5 lntrade_{i,t} + \xi_{i,t}} \qquad (\mathbf{3})\end{aligned}$$

Where the subscripts $\boldsymbol{i}$ and $\boldsymbol{t}$ represent an individual ($i = 1 \cdots 21$) and the time period ($t =$ 1990 à 2019) respectively. $\boldsymbol{\alpha_0\ et\ \delta_0}$ the constants, $\alpha_{1-6}\ et\ \delta_{1-5}$ are not only the parameters associated with the variables but also the elasticities, $\boldsymbol{\tau_{i,t} = \mu_{i,t} + \nu_{i,t}, et\ \ \xi_{i,t} = \varsigma_{i,t} + \varrho_{i,t}}$, $\boldsymbol{\mu_{i,t}\ \approx (0, \sigma_2\mu)\ et\ \nu_{i,t} \approx (0, \sigma_2 \upsilon)}$ are independent of each other and of each other, the same for $\boldsymbol{\varsigma_{i,t}\ et\ \varrho_{i,t}}$.

Raising the income level squared consists of checking the robustness of the equation $(\mathbf{1})$ and following trivial facts, such as that several empirical studies conclude that there is a non-linear relationship between environmental quality and income level (e.g.: Ahmed et al. 2016; Begum et al. 2015 and Shahbaz et al. 2015).

The empirical estimation strategy of our study is the PMG model[4] of Pesaran, Shin and Smith (1999). The latter takes the cointegration form of the simple ARDL model[5] and adapts it to a panel setting, allowing the constants, short term coefficients and cointegration terms to be different across individuals. According to Rawshan et al. (2015), Djepang and Tchoumo (2020), the main features of this technique include: (**i**) a cointegrating relationship estimated using ordinary least squares (OLS) and an estimation performed after selecting the

[3] Originally developed by Ehrlich and Holden (1971;1972) with some modifications to take into account the endogeneity of variables.
[4] Pooled Mean Group.
[5] Autoregressive distributed lags.

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respective lag order appropriate for the model: (**ii)** an applied technique that remains statistically significant regardless of the order of integration (I(0), I(1) or I(0) and I(1)), which generally explains the position that unit root tests may not be necessary, despite the approaches of Johansen and Jeslius; (**iii)** a requirement that the test be valid when the period (T) of the study is greater than the sample size (N), and both (T and N) must be finite, (**iv)** the consideration of time dynamics (adjustment lag, expectations,…) in the explanation of the variables, (v) a requirement that the test be valid when the period (T) of the study is greater than the sample size (N), and both (T and N) must be finite,) in the explanation of the variables, thus improving the forecasting and effectiveness of policies (decisions, actions,…).

Specifically, the PMG model can be formulated as follows:

$$\Delta y_{i,t} = \phi_i EC_{i,t} + \sum_{j=0}^{q-1} \Delta X_{i,t-j} * \beta_{i,j} + \sum_{j=1}^{p-1} \lambda_{i,j} * \Delta y_{i,t-j} + \epsilon_{i,t} \qquad (4)$$

With:

$$EC_{i,t} = y_{i,t-1} - X_{i,t} * \theta \qquad (5)$$

q *et* p the lag levels of the exogenous variables and the endogenous variable respectively , Δ is the first difference operator, X is the matrix of exogenous variables, EC is the error correction term that represents the speed of readjustment of the model to the long-run equilibrium when it is affected by shocks.

The ARDL panel formulations of equations (2) and (3) above are specified as follows:

$$\Delta lneq_{i,t} = \alpha'_0 + \alpha'_1 lneq_{i,t-1} + \alpha'_2 lnrenc_{i,t-1} + \alpha'_3 lnenc_{i,t-1} + \alpha'_4 lneg_{i,t-1} + \alpha'_5 lnurbg_{i,t-1} + \alpha'_6 lnfd_{i,t-1} + \alpha'_7 lntrade_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{i,j} * \Delta lneq_{t-j} + \sum_{j=0}^{q-1} \beta_{i,j} * \Delta X_{i,t-j} + \tau_{i,t} \qquad (6)$$

$$\Delta lneq_{i,t} = \delta'_0 + \delta'_1 lneq_{i,t-1} + \delta'_2 lneg_{i,t-1} + \delta'_3 lneg^2_{i,t-1} + \delta'_4 lnurbg_{i,t-1} + \delta'_5 lnfd_{i,t-1} + \delta'_6 lntrade_{i,t-1} + \sum_{j=1}^{p-1} \psi_{i,j} * \Delta lneq_{t-j} + \sum_{j=0}^{q-1} \varrho_{i,j} * \Delta X_{i,t-j} + \xi_{i,t} \qquad (7)$$

The effect of the non-linearity of urbanization and financial development will be analysed in our work through the following model:

$$\Delta lneq_{i,t} = \alpha'_0 + \alpha'_1 lneq_{i,t-1} + \alpha'_2 lnrenc_{i,t-1} + \alpha'_3 lnenc_{i,t-1} + \alpha'_4 lneg_{i,t-1} + \alpha'_5 lnurbg_{i,t-1} + \alpha'_6 lnurbg^2_{i,t-1} + \alpha'_7 lnfd_{i,t-1} + \alpha'_8 lnfd^2_{i,t-1} + \alpha'_9 lntrade_{i,t-1} + \sum_{j=1}^{p-1} \lambda_{i,j} * \Delta lneq_{t-j} + \sum_{j=0}^{q-1} \beta_{i,j} * \Delta X_{i,t-j} + \tau_{i,t} \qquad (8)$$

3.4. Methodological approach

The methodological approach involved the following steps: (**i)** the study of the statistics and correlation between the variables, (**ii**) the verification of the dependence between

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individuals, the study of stationarity and the determination of the optimal number of lags, (**iii**) performing the cointegration test to verify if there is a long term relationship between the variables, (**iv**) estimating the coefficients of the parameters of equations (6), (7) and (8) in order to implement the causality test, (**v**) proceeding with the variance decomposition.

4. Empirical Results and Discussion

4.1. Characteristics and Correlation between Variables

This section presents the summary of the descriptive statistics and the correlation matrix of the variables used in the estimations. The aim is to have information on the past behaviour of each of the variables in the series before undertaking an in-depth analysis. Table 2 below presents a summary of the results on the characteristics of the variables. Of the variables under study, it should be noted that they are all non-Gaussian (non-normal), In addition, environmental quality, renewable energy consumption and financial development are the most dispersed (77,08%, 22,23% and 34,34% respectively) in terms of the coefficient of variation, which has the advantage of not considering the units of the variables, unlike the standard deviations.

For all variables, the inter-individual variability is greater than the intra-individual variability. This implies that there is heterogeneity in the data.

Table 2: Statistical results for each of the variables

	LNEQ	LNRENC	LNENC	LNEG	LNURBG	LNTRADE	LNFD
Mean	1.793478	5.57746	7.898837	7.39722	15.41975	4.163515	2.650204
Median	1.60342	5.168289	7.684951	7.189944	15.51669	4.179862	2.63621
Maximum	6.094134	8.487083	10.28614	9.388427	18.44836	5.055365	4.665892
Minimum	-1.609438	3.553927	5.956475	5.301469	12.88989	2.405814	-0.800325
Stand. dev.	1.382472	1.244244	1.022673	0.951118	1.218858	0.442825	0.910288
CV	0.770832	0.223084	0.129471	0.128577	0.079045	0.106358	0.343478
Jarque-Bera	252.4089	38.41054	24.19301	20.61206	6.579916	75.41215	40.70249
Probability	0.000000	0.000000	0.000006	0.000033	0.037255	0.000000	0.000000
observations	629	524	630	630	630	608	613

Note: CV = coefficient of variation

The purpose of correlation is to discover the nature of the relationship between the variables, the results obtained are reported in Table 3.

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Table 3: Correlation matrix between variables

Variables	lneq	lnrenc	lnenc	lneg	lnurbg	lntrade	lnfd
lneq	1						
lnrenc	0.334 (0.000)	1					
lnenc	0.454 (0.000)	0.92 (0.000)	1				
lneg	0.38 (0.000)	0.732 (0.000)	0.878 (0.000)	1			
lnurbg	0.635 (0.000)	-0.302 (0.000)	-0.301 (0.000)	-0.381 (0.000)	1		
lntrade	-0.216 (0.000)	0.421 (0.000)	0.402 (0.000)	0.435 (0.000)	-0.55 (0.000)	1	
lnfd	0.23 (0.000)	0.616 (0.000)	0.621 (0.000)	0.467 (0.000)	-0.27 (0.000)	0.354 (0.000)	1

Note: (.) probability value

Some exogenous variables (lnrenc, lnenc, lneg, lnurbg, lnfd) are positively correlated with the endogenous variable (lneq). However, the intensity of this correlation is not the same, Urbanization (0,635) is strongly correlated with environmental quality. In contrast, only commercial openness is negatively correlated. Moreover, the probability of each of these exogenous variables is zero, which implies that they are significant. This conclusion cannot be accepted at this stage, as a correlation is not proof of causality. There are usually omitted factors that are responsible for the observed associations between the variables.

4.2. Tests for dependence and homogeneity between individuals

This section presents the results of the dependence and homogeneity tests, as well as the Haussmann test. When working with panel data, it is important to check for dependence and homogeneity between individuals before any careful and in-depth analysis of the series. This is because of the geographical proximities and socio-economic similarities that may exist between the countries under study. The econometric literature proposes a set of tests to verify the existence of dependence or not. In the context of this study, we will retain those of Breusch-Pagan LM (1980), Pesaran scaled LM (2004), Baltagi, Feng and Kao (2012), Pesaran CD (2004). The results are summarised in Table 4 below, with the null hypothesis of no dependence between individuals. The results of these four dependence tests under the consecutive estimation of fixed and random effects show that the null hypothesis is rejected for all models. This also confirms the conclusion of the descriptive statistics study that the data are heterogeneous.

Table 4: Test of cross-section dependence

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Tests	lneq	lnrenc	lnenc	lneg	lnurbg	lntrade	lnfd
Breusch-Pagan LM	3355.5** (0.000)	214.4** (0.000)	2234.8** (0.000)	3277.6** (0.000)	6037.3** (0.000)	936.95** (0.000)	1901.2** (0.000)
Pesaran scaled LM	153.48** (0.000)	95.36** (0.000)	98.8** (0.000)	149.68** (0.000)	284.3** (0.000)	35.47** (0.000)	82.52** (0.000)
Baltagi. Feng and Kao (Bias-corrected scaled LM)	153.12** (0.000)	94.93** (0.000)	98.44** (0.000)	149.32** (0.000)	283.9** (0.000)	35.1** (0.000)	82.16** (0.000)
Pesaran CD	46.53** (0.000)	27.32** (0.000)	16.98** (0.000)	34.32** (0.000)	77.62** (0.000)	9.48** (0.000)	31.66** (0.000)

**** Significant at 5% level**

Working with panel data requires attention to the existence of a correlation between the error term and the exogenous variables, because of the dependence between individuals in the sample. This effect may be fixed or random. The question is therefore whether to estimate a model with a fixed effect or a random effect. The null hypothesis to be specified is to test the absence of correlation between the specific error and the random variables.

Table 5: Hausman test

Test summary	Chi-square statistic	Chi-square df	Probably.
cross-section random	22.496**	6	0.001

**** Significant at 5% level**

Table 5 shows the results of this test. The probability is less than 5%, hence the decision is to reject the null hypothesis and accept the alternative hypothesis.

4.3. Results of the Unit Root and Cointegration Tests

In this section, we present the results of the stationarity and cointegration tests between the variables. Well before, those of the choice of the optimal number of lags are proposed. Several information criteria (AIC, LR, FPE, SC and HQ) of choice are proposed, as shown in the results of Table 6 below. The choice of the optimal lag is the one whose estimated model offers the minimum value of one of the stated criteria. It can be seen, therefore, that this is the criterion of AIC (-20,41), hence the optimal choice of lag 3 is the one chosen.

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Table 6: Selection of the optimal delay

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1785.054	NA	0.000173	11.20033	11.28277	11.23325
1	2827.443	8994.368	7.08E-17	-17.32152	-16.66206	-17.05818
2	3358.606	1012.529	3.48E-18	-20.33503	**-19.0986***	**-19.8413***
3	3420.003	114.3524	**3.22e-18***	-20.**4125***	-18.59901	-19.68835
4	3455.008	63.66535	3.52E-18	-20.32505	-17.93452	-19.37047
5	3493.229	**67.84188***	3.78E-18	-20.25768	-17.29013	-19.07268

indicates the order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

The next step is to test the stationarity of the variables and for cointegration. When handling panel data it is important to know the properties of each of the variables to tend towards good estimates. Since the pioneering work of Levin and Lin (1992), the literature on non-stationary panel data econometrics (particularly, on cointegration tests) has grown considerably. The addition of the individual dimension to the time dimension is of great interest for the analysis of non-stationary series. The unit root and cointegration tests on panel data are indeed more powerful than on time series. Concerning the properties of the variables in this study, the tests of Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003), ADF and PP are jointly used, referring to the Fisher statistic (Maddala and Wu, 1999). The results are presented in Table 7, where it can be seen that some variables are stationary in level while all are stationary in the first difference.

Table 7: Results of the unit root test

Variables	lneq	lnrenc	lnenc	lny	lnurbg	lntrade	lnfd
			I(0)				
Levin. Lin. and Chu t*	-2.207**	-2.071**	-1.21	1.191	-7.215**	-2.196**	-2.575**
Im. Pesaran. and Shin W-stat	1.845	3.848	0.608	5.422	2.692	-1.837**	-1.133
ADF-Fisher Chi-square	37.16	32.41	32.77	13.94	68.61**	57.084*	56.14*
PP-Fisher Chi-square	43.11	34.3	33.76	14.34	167.49**	53.08	56.25*
			I(1)				
Levin. Lin. and Chu t*	-17.9**	-16.34**	-9.36**	-9.36	-1.697**	-20.27**	-17.35**
Im. Pesaran. and Shin W-stat	-19.34**	-15.87**	-13.09**	-10.55	-4.292**	-19.22**	-17.97**
ADF-Fisher Chi-square	364.9**	288.83**	244.25**	192.4	110.07**	358.77**	332.9**
PP-Fisher Chi-square	422.9**	361.15**	431.56**	209.18	101.83**	400.96**	319.06**

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Note: **,* significant at 5% and 10% respectively,

The interpretation of cointegration tests continues to be of growing interest in empirical work. We can highlight works such as Levin and al. (2022), Chang and Nguyen (2012), Pesaran and Yamagata (2008), Ando and Bai (2015), Baltagi and Kao (2001), Baltagi and al. (2016; 2017), Olatunji and Asongu (2021), which conclude that a variable can have a unit root and not admit an equilibrium relationship in the long run. The econometric literature proposes some tests (Pedroni 1995, 1997, 1999, 2003; Kao 1999; Bai and Ng 2001) to check cointegration on panel data. In this study, the Kao (1999) test[6] is used to verify the null hypothesis of no cointegration. Unlike Pedroni's test[7] , Kao considers the special case where the cointegrating vectors are assumed homogeneous between individuals. Table 8 presents the results, which makes it possible to reject the null hypothesis at the expense of the alternative hypothesis of the presence of autocorrelation. There is therefore a long-term equilibrium relationship between the variables.

Table 8: Result of the Kao cointegration test

Test	t-statistic	Probability.
ADF	-3.664**	0.0001

**** Significant at 5% level**

The different results of the preliminary tests led us to estimate the parameters of the specified models.

4.4. Estimation of Model Coefficients

This section presents the results of the estimation of the parameters of equations (6), (7) and (8). They are summarised in Table 9 and concerns the long and short-run elasticities.

In the long term, equation (6) shows that, in the panel of countries considered, primary energy consumption, economic growth, urbanization and international trade significantly improve the quality of the environment. An increase of, say, 1% in each of these variables improved the environment by 72,5%, 2,6%, 9,1% and 15,2% respectively. These results are in line with those of Al-Mulali and Sab (2012a), Arouri and al. (2012), Saidi and Hammami (2015a, b), Yang and Lin (2016) for primary energy consumption; Guo et al. (2018), Boggia and al. (2014), Siva and al. (2016) for economic growth; Pata (2018), Ren and al. (2015), Shahbaz and al. (2014), Kwakwa and Alhassan (2018) for urbanisation; and Djepang and Tchoumo (2020); Zamil and al. (2019), Frutos-Bencze and al. (2017). In the short term,

[6] Dickey-Fuller type test and Dicker-Fuller Augmented type test.

[7] Pedroni (1995, 1997) has proposed various tests aimed at capturing the null hypothesis of the absence of intra-individual cointegration for both homogeneous and heterogeneous panels, He proposes (1999, 2003) an extension to the case where the cointegration relationships include more than two variables.

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however, only primary energy consumption has a significant positive impact on environmental quality.

The EKC hypothesis (equation 7) is not validated. Despite the positivity and significance of the income level coefficient, the squared coefficient does not have the expected sign. However, urbanization, international trade and financial development are positive and significant in the long run. Only income level is positively significant.

Regarding the test of the hypothesis of inverted U-shaped curve between urbanization and financial development, the results (equation 8) show that this hypothesis is not validated. This means that the peak has not yet been reached for sub-Saharan African countries. In addition, the primary energy consumption and international trade are positive and significant in the long run, while only primary energy consumption is positive and significant in the short run.

Also, for each model, the coefficient of the error correction term is negative and significant. This implies that in case the models ((6), (7) and (8)) are affected by shocks, the speed of adjustment in the short run to reach equilibrium is significant. In other words, when CO_2 emissions per capita are above or below their equilibrium value, they would adjust by 38,2%, 31% and 2,41% per year respectively.

Table 9: Estimation of the short-run and long-run elasticities

Dependent Vble: d(lneq)			
	Long-term panel elasticities		
Variables	**(6)**	**(7)**	**(8)**
lnrenc	-0.024		-0.024
	(0.743)		(0.743)
lnenc	**0.725****		**0.725****
	(0.000)		**(0.0000)**
lneg	**0.026****	**1.21****	0.026
	(0.000)	**(0.000)**	(0.788)
lneg2		**0.606****	
		(0.000)	
lnurbg	**0.91****	**0.148****	**0.917****
	(0.000)	**(0.0469)**	**(0.0000)**
			0.458**
Lnurbg2			**(0.0000)**
lntrade	**0.152****	**0.092***	**0.152****
	(0.0035)	**(0.056)**	**(0.0035)**
lnfd	0.023	**0.278****	0.023
	(0.445)	**(0.000)**	(0.445)
			0.011
Lnfd2			(0.445)

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	Short-term panel elasticities		
d(lnrenc)	0.035		-0.0351
	(0.752)		(0.752)
d(lnenc)	**0.268****		**0.268****
	(0.0031)		**(0.0031)**
d(lneg)	0.15	**0.44****	0.150
	(0.646)	**(0.000)**	(0.646)
d(lneg2)		0.222	
		(0.19)	
d(lnurbg)	8.23	-5.29	8.234
	(0.241)	(0.196)	(0.241)
d(lnurbg2)			4.117
			(0.241)
d(lntrade)	-0.0076	0.019	-0.007
	(0.928)	(0.813)	(0.928)
d(lnfd)	0.02	-0.05	0.020
	(0.659)	(0.143)	(0.659)
d(lnfd2)			0.01
			(0.659)
c	**-7.55****	**-3.00****	**-7.558****
	(0.000)	**(0.000)**	**(0.0000)**
ECM	**-0.382****	**-0.31****	**-0.0241****
	(0.000)	**(0.000)**	**(0.0000)**

Note: **, * significant at 5% and 10% respectively

The analysis of the parameter estimation results shows that sub-Saharan Africa, primary energy consumption, economic growth, urbanization and international trade are factors that negatively influence environmental quality. Also, in case of shocks, the speed of adjustment of the system in the short term to reach equilibrium is significant. Notably, the EKC hypothesis is not validated, nor is the non-linear link between urbanization and financial development on environmental quality. If the panel results are moderately acceptable, what about the short-term elasticities of each country?

The answer to this question is summarised in table 10.

Table 10: Short-term elasticities by country

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Variables	ECM	d(lnrenc)	d(lnenc)	d(lneg)	d(lnurbg)	d(lntrade)	d(lnfd)	c
				-				
Angola	-0.291**	0.08**	0.544**	0.441**	14.17	0.039**	-0.082**	-6.141**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.265)	(0.000)	(0.000)	(0.024)
Benin	-0.31**	0.272	0.27	1.299	-1.082	-0.571*	0.021	-4.31
	(0.000)	(0.149)	(0.136)	(0.170)	(0.752)	(0.093)	(0.809)	(0.182)
Botswana	-0.186**	0.272	0.27	1.29	-1.082	-0.057*	0.021	-3.46
	(0.000)	(0.149)	(0.136)	(0.170)	(0.1703)	(0.093)	(0.809)	(0.651)
Cameroon	-0.865**	-0.189**	-0.176*	0.804	130.25	-0.279**	7.6E-05	-4.424**
	(0.000)	(0.046)	(0.056)	(0.518)	(0.849)	(0.0004)	(0.9975)	(0.021)
RDC	0.86**	-0.826**	1.068**	-2.588	11.78	0.015	0.126**	-0.36
	(0.0042)	(0.047)	(0.006)	(0.597)	(0.977)	(0.133)	(0.0006)	(0.742)
Congo	0.091**	-0.267**	0.45**	1.34	-3.167	-0.191**	0.144**	1.811
	(0.0028)	(0.0115)	(0.008)	(0.108)	(0.983)	(0.0073)	(0.0023)	(0.71)2
Ivory Coast	-0.165**	-0.203*	0.689*	0.63	6.105	0.289**	0.24**	-3.331
	(0.0064)	(0.052)	(0.0002)	(0.199)	(0.680)	(0.013)	(0.0025)	(0.721)
Gabon	0.052**	0.49**	-0.126**	0.616**	4.259	-0.085**	-0.085**	0.833
	(0.022)	(0.023)	(0.0103)	(0.016)	(0.864)	(0.0006)	(0.0006)	(0.830)
Ghana	-0.318**	1.6	-0.597**	1.6	-9.558	-0.363**	0.287**	-5.722
	(0.0006)	(0.129)	(0.0029)	(0.129)	(0.885)	(0.0008)	(0.0002)	(0.449)
Kenya	-0.363**	-0.66**	0.749**	0.32	8.79	-0.139**	0.07**	-7.09
	(0.0002)	(0.0033)	(0.0005)	(0.447)	(0.876)	(0.004)	(0.0038)	(0.349)
Mauritius	-0.144**	-0.78**	0.32**	-0.12	1.69	0.17**	0.003	-2.662
	(0.0069)	(0.047)	(0.0003)	(0.850)	(0.950)	(0.0024)	(0.785)	(0.750)
Mozambique	-0.21**	-0.137**	0.232**	-1.63**	7.12	-0.289**	-0.247**	-4.305
	(0.000)	(0.0017)	(0.0009)	(0.019)	(0.675)	(0.002)	(0.0006)	(0.118)
Namibia	-0.114**	0.223**	-0.017	-1.46**	-3.01	-0.086*	0.263*	-1.954
	(0.0007)	(0.0229)	(0.348)	(0.030)	(0.890)	(0.090)	(0.0006)	(0.504)
Nigeria	-0.057**	-0.126**	0.33**	0.901**	-13.45	0.121**	0.023**	-0.443
	(0.0005)	(0.0073)	(0.000)	(0.04)	(0.74)	(0.000)	(0.008)	(0.68)
Senegal	-0.217**	0.285**	0.157**	0.949**	0.099	0.028*	0.115**	-4.109
	(0.0005)	(0.0001)	(0.0027)	(0.008)	(0.986)	(0.057)	(0.0004)	(0.461)
South Africa	-0.454**	-0.078	0.256*	0.145	-1.843	0.084**	0.0007	-8.129
	(0.0016)	(0.408)	(0.058)	(0.89)	(0.898)	(0.029)	(0.95)	(0.61)
Sudan	-0.87**	0.039	0.0310	0.547**	-3.601*	0.243**	-0.246**	-16.03*
	(0.000)	(0.145)	(0.181)	(0.041)	(0.053)	(0.000)	(0.000)	(0.065)
Tanzania	-0.535**	0.083*	-0.0013	4.083*	-0.257	0.0262	-0.195**	-10.08
	(0.0005)	(0.075)	(0.985)	(0.081)	(0.986)	(0.431)	(0.0001)	(0.468)
Togo	-0.87**	0.448**	0.227**	-0.306	52.29	1.423**	-0.433**	-18.75
	(0.0000)	(0.0119)	(0.0033)	(0.396)	(0.797)	(0.0008)	(0.0007)	(0.184)
Zambia	-0.688**	0.23*	1.147**	-2.31	-0.657	-0.253**	-0.03**3	-13.53
	(0.0003)	(0.091)	(0.039)	(0.108)	(0.857)	(0.004)	(0.025)	(0.436)
Zimbabwe	0.013**	0.239**	0.151	0.153**	10.87*	-0.016	-0.05**	-12.04*
	(0.000)	(0.0381)	(0.148)	(0.004)	(0.087)	(0.105)	(0.000)	(0.077)

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Note: **, * significant at 5% and 10% respectively; (.) probability, DRC = Democratic Republic of Congo.

The consumption of renewable energy has a positive and significant effect on the quality of the environment in the short term in certain countries (Angola, Gabon, Namibia, Senegal, Tanzania, Togo, Zambia and Zimbabwe), and a significant and negative effect in others (Cameroon, DRC, Congo, Ivory Coast, Kenya, Mauritius, Mozambique and Nigeria). The concern to preserve the environment using renewable energies is well considered in the second group of countries than in the first. For primary energy consumption, significance in Angola, DRC, Congo, Ivory Coast, Kenya, Mauritius, Mozambique, Nigeria, Senegal, South Africa, Togo and Zambia, while the opposite effect (negative significance) is found in Cameroon and Gabon. Improved economic growth negatively affects environmental quality in Angola, Mozambique and Namibia. It therefore has a positive and significant effect in Gabon, Nigeria, Senegal, Sudan, Tanzania and Zimbabwe. This can be explained by the idea that production activities take time to affect the environment. As for urbanisation, it is negatively significant in Sudan and positively significant in Zimbabwe. In Sudan, this can be explained by the long civil war that the state has experienced for decades. This has led people to commit environmental abuses in search of the basic necessities of life. In terms of international trade, there is a significant negative impact in Benin, Botswana, Cameroon, Congo, Gabon, Ghana, Kenya, Mozambique, Namibia and Zambia. It is positive and significant in Angola, Congo, Ivory Coast, Mauritius, Nigeria, Senegal, South Africa, Sudan and Togo. For financial development, the relationship with environmental quality is negative and significant in Angola, Gabon, Mozambique, Sudan, Tanzania, Togo and Zambia, Positive and significant in DRC, Congo, Ivory Coast, Ghana, Kenya, Namibia, Nigeria and Senegal.

Also in table 10, it is seen that the error correction term is negative and significant in Angola, Benin, Botswana, Cameroon, Côte d'Ivoire, Ghana, Kenya, Mauritius, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan, Tanzania, Togo and Zambia. This suggests that in the event of shocks to these countries, the speed of adjustment in the short run to reach equilibrium is significant, In other words, when CO_2 emissions per capita are above or below their equilibrium value, they would adjust by 29,1%, 31%, 18,6%, 86,5%, 16,5%, 31,8%, 36,3%, 14,4%, 21%, 11,4%, 5,7%, 21,7%, 45,4%, 87%, 53,5%, 87% and 68,8% per year respectively.

Considering these analyses from the data in Tables 9 and 10, the question of causality between urbanisation, financial development and environmental quality in sub-Saharan Africa arises. This is the subject of the next section.

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4.5. Panel and Country Causality Test

The existence of a cointegrating relationship implies that causality tests must be carried out. Basically, for two variables X_t and Y_t, X_t cause in the sense of Granger Y_t if the current and past information of X_t helps to improve the prediction of the variable Y_t. This definition is based on the dynamic relationship between the variables. In this case, a bivariate VAR with variables expressed in first difference to solve the causality problem is used. The results obtained are shown in Table 11.

Table 11: Causality test by country between urbanisation, financial development and environmental quality

	lnurbg→lneq	lneq→lnurbg	lnfd→lneq	lneq→lnfd	lnurbg→lnfd	lnfd→lnurbg
Panel	**2.351***	**11.17****	1.498	1.504	1.771	**4.243****
	(0.096)	**(2.00E-05)**	(0.224)	(0.223)	(0.171)	**(0.014)**
Angola	**2.79***	6.9	**5.63****	1.45	0.34	0.31
	(0.081)	(0.405)	**(0.012)**	(0.250)	(0.710)	(0.730)
Benin	2.51	2.22	0.29	**9.67****	**8.5****	**3.78****
	(0.120)	(0.130)	(0.740)	**(0.0009)**	**(0.0017)**	**(0.037)**
Botswana	1.66	0.85	0.74	0.28	**6.7****	0.47
	(0.210)	(0.430)	(0.480)	(0.750)	**(0.0051)**	(0.625)
Cameroon	**17.2****	**10.45****	**4.83****	**29.69****	**52.93****	**2.37****
	(3.00E-05)	**(0.0006)**	**(0.018)**	**(6.00E-07)**	**(4.00E-09)**	**(1.16E-01)**
RDC	**3.21***	**3.427****	2.39	0.528	1.22	1.69
	(0.058)	**(0.049)**	(0.121)	(0.598)	(0.310)	(0.210)
Congo	**7.95****	2.26	0.589	1.005	1.277	0.577
	(0.0024)	(0.126)	(0.562)	(0.382)	(0.298)	(0.569)
Ivory Coast	2.03	**39.59****	0.079	0.997	**4.927****	0.68
	(0.153)	**(4.00E-08)**	(0.924)	(0.384)	**(0.0166)**	(0.516)
Gabon	0.22	0.048	0.997	2.195	**2.94***	**3.39***
	(0.799)	(0.952)	(0.384)	(0.135)	**(0.073)**	**(0.052)**
Ghana	**8.847****	1.101	0.303	0.427	0.449	0.429
	(0.0014)	(0.349)	(0.741)	(0.657)	(0.643)	(0.656)
Kenya	2.144	**8.251****	0.911	0.811	1.154	**4.819****
	(0.140)	**(0.002)**	(0.416)	(0.456)	(0.332)	**(0.017)**
Mauritius	2.053	**9.496****	0.95	1.926	1.77	**2.576***
	(0.151)	**(0.001)**	(0.401)	(0.168)	(0.192)	**(0.097)**
Mozambique	0.124	2.284	**6.24****	2.0007	**3.323***	1.151
	(0.439)	(0.124)	**(0.0071)**	(0.159)	**(0.054)**	(0.236)
Namibia	**5.26****	**3.72****	1.017	**2.685***	**20.94****	0.649
	(0.0136)	**(0.040)**	(0.377)	**(0.0904)**	**(7.00E-06)**	(0.531)
Nigeria	2.233	0.29	1.875	0.166	**2.647***	0.084
	(0.129)	(0.750)	(0.176)	(0.847)	**(0.092)**	(0.919)
Senegal	**2.757***	**7.592****	0.091	**5.849****	**5.404****	2.546

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	(0.084)	**(0.0029)**	(0.912)	**(0.0088)**	**(0.0119)**	(0.1002)
South Africa	2.262	**11.048****	0.112	1.798	0.448	**3.81****
	(0.126)	**(0.0004)**	(0.894)	(0.190)	(0.580)	**(0.038)**
Sudan	**4.436****	**4.787****	2.065	2.286	1.996	0.135
	(0.023)	**(0.018)**	(0.149)	(0.124)	(0.158)	(0.873)
Tanzania	**8.438****	0.559	1.009	**3.142***	**7.287****	**4.108****
	(0.0018)	(0.579)	(0.379)	**(0.062)**	**(0.0035)**	**(0.029)**
Togo	**3.341***	1.112	0.025	3.893**	**2.934***	0.11
	(0.053)	(0.345)	(0.974)	(0.035)	**(0.073)**	(0.895)
Zambia	**5.393****	**4.315****	**6.928****	1.179	**10.062****	0.32
	(0.012)	**(0.025)**	**(0.0044)**	(0.325)	**(0.0007)**	(0.728)
Zimbabwe	**2.686***	1.6	**2.832***	1.202	0.44	**12.71****
	(0.089)	(0.223)	**(0.085)**	(0.323)	(0.650)	**(0.0004)**

**** significant at 5% and 10%; (.) probability, $X_t \rightarrow Y_t : X_t$ cause in the sense of Granger Y_t**

In terms of the relationship between urbanization and environmental quality, a unidirectional relationship (lnurbg→lneq) is observed in Angola, Congo, Ghana, Tanzania, Togo, Zambia and Zimbabwe. The opposite direction (lneq→lnurbg) is observed in Côte d'Ivoire, Kenya, Mauritius and South Africa. A bidirectional relationship is found in Cameroon, Namibia, Senegal, Sudan and Zambia.

For financial development and environmental quality, a unidirectional relationship (lnfd→lneq) is observed in Angola, Mozambique, Zambia and Zimbabwe. The opposite direction (lneq→lnfd) in Benin, Namibia, Senegal and Tanzania, A bidirectional relationship only in Cameroon.

A unidirectional relationship between urbanization and financial development (lnurbg→lnfd) is observed in Côte d'Ivoire, Gabon, Namibia, Nigeria, Senegal, Tanzania, Togo and Zambia. The opposite direction (lnfd→lnurbg) is found in Gabon, Kenya, Mauritius, South Africa, Tanzania and Zimbabwe, Only Cameroon has a two-way relationship.

In the panel, a bidirectional relationship is found between urbanization and environmental quality, while there is a unidirectional relationship between financial development and urbanisation.

4.6. Variance Decomposition

A VAR (Vector AutoRegressive) model essentially models the dynamic relationships between a group of variables chosen to characterise a particular economic phenomenon. Impulse analysis determines the influence of a shock related to the evolution of one of the variables on the other variables of the system. In other words, to analyse how one of the variables reacts (responses) to shocks or innovations (impulses) on the other variables in the model.

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The variance decomposition is simply a numerical analysis (in %) of the impulse responses. Its purpose is to analyse the contribution of the innovation of one of the variables to the variance of the forecast error at a fixed horizon of the other given variables. In the case of this study, the aim is to capture the weight of shocks to the innovations of the variables lnrenc, lnenc, lneg, lnurbg, lntrade and lnfd in the variability of the forecast error at horizon 10 of the quality of the environment. The results of the panel variance decomposition are shown in Table 12.

Table 12: Variance decomposition of the panel

Period	std dev	lneq	lnrenc	lnenc	lneg	lnurbg	lntrade	lnfd
Variance decomposition of lneq								
1	0.135377	100	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.18565	99.42547	0.020071	0.017692	0.245284	0.000684	0.033555	0.257248
3	0.220304	98.65409	0.017059	0.023781	0.668495	0.002134	0.050616	0.583823
4	0.246736	97.75859	0.014034	0.036384	1.17816	0.002992	0.06859	0.941248
5	0.267889	96.7866	0.011973	0.057873	1.741613	0.003014	0.087507	1.311418
6	0.285345	95.755	0.01165	0.091442	2.348013	0.002659	0.109059	1.682180
7	0.300076	94.67426	0.013681	0.139727	2.991083	0.002903	0.134320	2.04403
8	0.312725	93.55225	0.018619	0.204786	3.665622	0.005011	0.164156	2.389552
9	0.323745	92.39575	0.026958	0.287956	4.366625	0.010355	0.199249	2.713108
10	0.333463	91.21077	0.039121	0.389827	5.08921	0.020301	0.240119	3.010653
Variance decomposition of lnrenc								
1	0.099753	1.107782	98.89222	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.139335	1.053339	96.68079	1.257919	0.807016	0.000227	0.146103	0.054608
3	0.171448	1.020146	94.42456	2.713962	1.491346	0.003942	0.190558	0.155489
4	0.199183	0.956197	92.00743	4.52115	2.005555	0.011453	0.233443	0.264773
5	0.224255	0.884152	89.54088	6.541488	2.375902	0.022828	0.270081	0.364672
6	0.247485	0.814391	87.06237	8.688597	2.642039	0.037597	0.304407	0.450596
7	0.269347	0.750924	84.61216	10.8892	2.832804	0.055254	0.337904	0.521754
8	0.290123	0.694888	82.22309	13.08806	2.968385	0.075312	0.371387	0.578882
9	0.309989	0.646188	79.92013	15.2449	3.062926	0.097342	0.405185	0.623333
10	0.329059	0.604242	77.72037	17.33177	3.126594	0.120977	0.439357	0.65669
Variance decomposition of lnenc								
1	0.115791	7.960426	8.805633	83.23394	0.000000	0.000000	0.000000	0.000000
2	0.159656	9.758342	13.62015	75.18102	1.116637	0.051089	0.173305	0.09946
3	0.192846	10.35099	14.81081	72.05204	2.309233	0.120691	0.12278	0.233467
4	0.219835	10.54984	15.53039	70.05814	3.217387	0.211413	0.095256	0.337568
5	0.242683	10.56603	15.99354	68.72183	3.903776	0.314048	0.086483	0.414289
6	0.262538	10.49312	16.33217	67.75342	4.437575	0.422451	0.091086	0.470178
7	0.280124	10.37447	16.59633	67.01158	4.869399	0.531942	0.105401	0.510873
8	0.295925	10.23242	16.81227	66.41726	5.231644	0.6393	0.126809	0.540306

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9	0.310281	10.07907	16.99472	65.92426	5.54493	0.742416	0.153405	0.561199
10	0.323439	9.921278	17.15278	65.50409	5.822629	0.840006	0.18374	0.575474
Variance decomposition of lneg								
1	0.035525	3.568316	3.912988	0.142968	92.37573	0.00000	0.00000	0.00000
2	0.058466	4.263888	3.558101	0.461529	91.28899	2.37E-07	0.239298	0.188196
3	0.077223	4.13466	3.576695	0.847948	90.74512	0.000991	0.421974	0.272615
4	0.09309	3.859801	3.683346	1.309673	90.30149	0.004001	0.559311	0.282382
5	0.106929	3.562298	3.821767	1.832047	89.84696	0.008866	0.66846	0.259605
6	0.119309	3.274531	3.972241	2.398158	89.35367	0.015091	0.759919	0.226385
7	0.130606	3.006645	4.126308	2.992362	88.81971	0.022172	0.839337	0.193467
8	0.14107	2.761455	4.279817	3.601319	88.25192	0.029688	0.909821	0.165985
9	0.15087	2.53896	4.430578	4.214126	87.65959	0.037315	0.973164	0.146271
10	0.160129	2.338022	4.577395	4.822137	87.05195	0.044813	1.030475	0.135204
Variance decomposition of lnurbg								
1	0.003528	0.385926	0.025765	0.128947	1.064401	98.39496	0.000000	0.000000
2	0.007476	0.141538	0.038903	0.176699	1.311885	97.97642	0.299606	0.054945
3	0.011896	0.119612	0.048515	0.312613	1.446514	97.3872	0.583677	0.101869
4	0.016606	0.181506	0.059255	0.523018	1.547025	96.71026	0.842953	0.135985
5	0.021501	0.312269	0.070772	0.796546	1.63005	95.94318	1.08442	0.162762
6	0.026513	0.508539	0.082559	1.122842	1.701044	95.08755	1.311587	0.185882
7	0.031604	0.766519	0.094238	1.491864	1.762333	94.15166	1.525853	0.207531
8	0.036745	1.080954	0.105532	1.89418	1.815166	93.14757	1.727565	0.229034
9	0.04192	1.445587	0.116246	2.321192	1.860374	92.08873	1.91665	0.251221
10	0.047118	1.853701	0.126247	2.765277	1.898617	90.9886	2.092933	0.274622
Variance decomposition of the lntrade								
1	0.133315	0.315375	0.30143	0.696775	0.081495	0.69077	97.91415	0.00000
2	0.175812	0.181764	0.174369	0.96057	0.273801	0.6903	97.60144	0.11776
3	0.203856	0.145046	0.145458	0.977984	0.402867	0.692998	97.43422	0.20143
4	0.22431	0.156241	0.154516	0.959503	0.483738	0.698064	97.28447	0.263466
5	0.23986	0.200907	0.192367	0.932828	0.533066	0.704238	97.12265	0.313946
6	0.252002	0.271336	0.25462	0.90779	0.562712	0.710696	96.9355	0.357351
7	0.261659	0.362362	0.338998	0.887354	0.58022	0.716874	96.7181	0.396088
8	0.269449	0.469891	0.443632	0.872315	0.590158	0.722386	96.47013	0.431487
9	0.275806	0.590359	0.566767	0.8627	0.595323	0.726974	96.19357	0.464311
10	0.281049	0.720541	0.706624	0.858328	0.597463	0.730475	95.89157	0.494999
Variance decomposition of the Lnfd								
1	0.183545	3.26E-05	1.764229	0.880333	0.06268	0.221227	0.333854	96.73764
2	0.267389	0.012178	0.901553	0.948496	2.258912	0.306175	1.38016	94.19253
3	0.327404	0.045304	0.601491	1.592051	4.037958	0.36820	2.344066	91.01093
4	0.372898	0.14192	0.480989	2.47644	5.036825	0.409423	3.162506	88.2919
5	0.40876	0.266332	0.447277	3.529129	5.534789	0.435242	3.903637	85.88359

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6	0.437911	0.402036	0.466962	4.693137	5.740534	0.448972	4.58598	83.66238
7	0.462224	0.541109	0.524498	5.92441	5.778407	0.453285	5.21758	81.56071
8	0.482939	0.67906	0.611241	7.187238	5.720399	0.450481	5.801009	79.55057
9	0.500893	0.813019	0.721472	8.453477	5.608849	0.442565	6.337046	77.62357
10	0.516675	0.941091	0.850919	9.70162	5.469231	0.431246	6.82617	75.77972

From the results of Table 12 and the graphs in figure 1, the variance of the forecast error of environmental quality can be explained by its own innovations at 91,21%, as well as those of the variables lneg and lnfd at 5,08% and 3,01% respectively. It goes without saying that economic growth and financial development would be systematically more explanatory in the variability of environmental quality, in contrast to the rest of the exogenous variables.

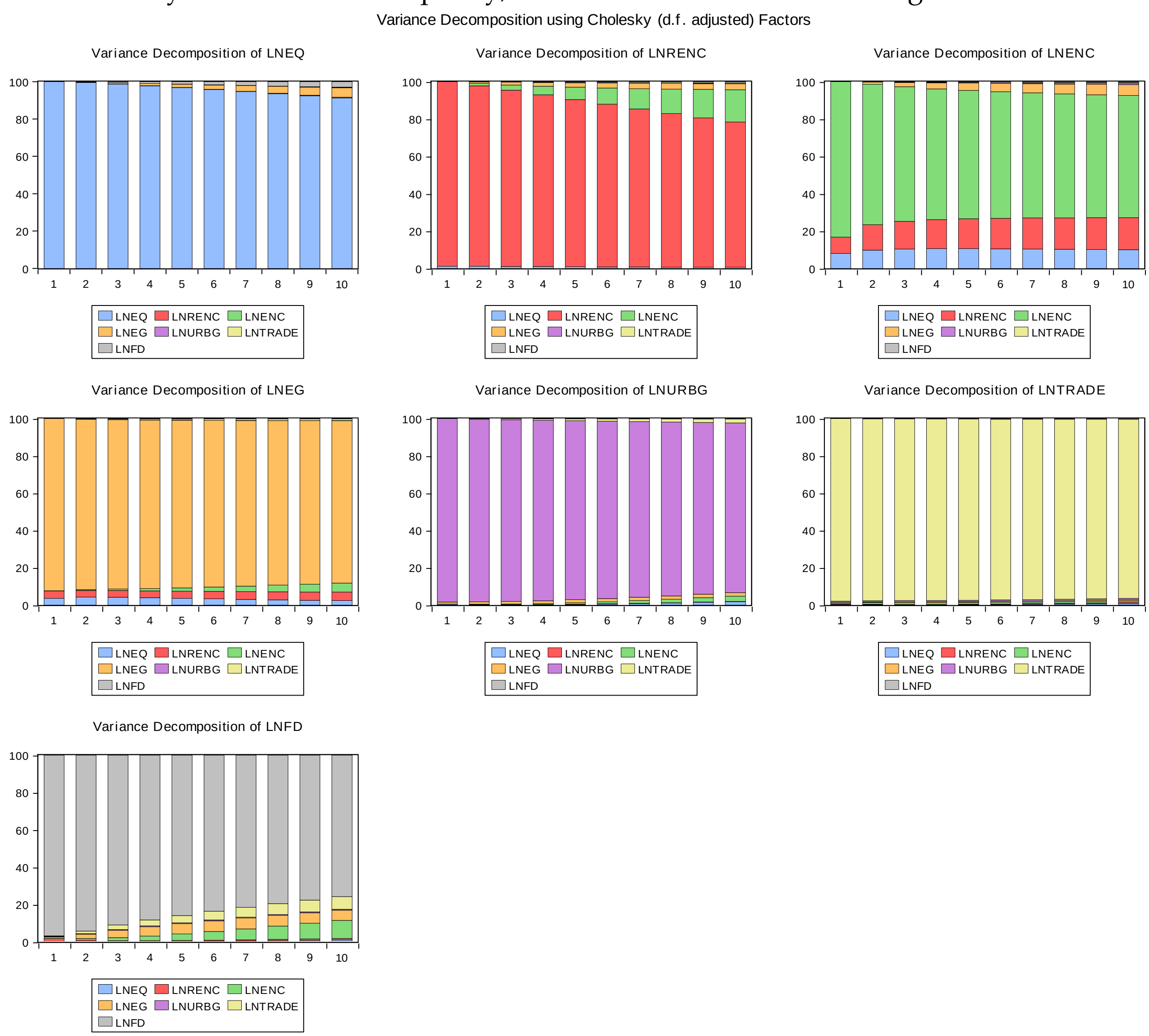

Figure 1: Panel variance decomposition plot using Cholesky factors (adjusted degree of freedom)

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The tenth-period histogram of each graph in figure 1 gives a quick overview of the weight of innovation shocks of certain variables in the variability of the forecast error of other variables. The graph for lntrade, for example, shows that most of the variance in the forecast error is explained by its own innovations. For lnenc, there would be lnenc, lnrenc, lneq and lneg, Lneg would be affected by lneg, lnrenc, lnenc and lneq, Lnurbg will be affected by lnurbg, lnenc and lneg. The variability of lnfd will come from lnfd, lnenc, lntrade and lneg.
With regard to the analysis and interpretation of the results obtained, some points of similarity and difference can be raised with previous work. The differences can be explained by the estimation methods, the study contexts, the sample sizes, and the nature of the data, while the similarity is noted in the quality of the variables used in most of the studies.

5. Conclusion and Policy Implications

5.1. Summary of finding and discussion

Urbanization and financial development are undoubtedly among the factors that will influence economic development according to projections by national and international institutions. The present study aimed to investigate the effects of these two factors on the quality of the environment in sub-Saharan Africa. In addition to these two variables of interest, and based on the empirical literature reviewed, other variables were incorporated into the analysis. These include renewable and primary energy consumption, GDP per capita and trade openness. The methodology used first questioned the quality of the data through a set of preliminary tests, before applying the PMG method to the STIRPAT and EKC models on a panel of 21 countries covering the period 1990-2019.
The empirical results obtained show that in the long run, primary energy consumption, economic growth, urbanization, and trade openness deteriorate environmental quality in sub-Saharan Africa, while in the short run, only primary energy consumption has an influence. Moreover, the error correction term has a negative sign and is otherwise significant. This implies that there is indeed an error correction mechanism: deviations from the long-run relationship induce changes in the evolution of environmental quality, urbanization, or financial development in the short run so as to force the system to converge towards its long-run equilibrium. Furthermore, the validation test of the EKC model was not conclusive. There is therefore no inverted U-curve between economic growth and environmental quality for this panel. Finally, the test of the EKC hypothesis in relation to various explanatory variables, notably urbanization and financial development, was also inconclusive, implying there is not a non-linear relationship between urbanisation, financial development and environmental quality. On the other hand, the Granger causality test yielded a bi-directional causal relationship between urbanization and environmental quality, and a unidirectional relationship between financial development and urbanisation.

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Also, the variance decomposition informed us that the variance of the prediction error of environmental quality can be explained by its own innovations at 91,21%, as well as those of the variables lneg and lnfd at 5,08% and 3,01% respectively. It goes without saying that economic growth and financial development would be systematically more explanatory in the variability of environmental quality, in contrast to the rest of the exogenous variables.

5.2. Implications of the research and recommendations

This study demonstrates that, according to the EKC hypothesis, the threshold at which a decrease in CO_2 emissions and an increase in income level is not yet reached for sub-Saharan African countries. These two factors are still in their ascending phase, to achieve the recommendations, states must: (i) reduce their consumption of primary energy (fossil fuels) and commit to strategies that are sustainable in nature, including green investment; (ii) define strict policies to encourage the use of public transport, particularly in urban areas; (iii) integrate environmental improvement and preservation into the development of trade policies; (iv) become fundamentally involved in the production and diversification of renewable energies; (v) encourage financial institutions to direct funding towards projects that promote green investment.

Sub-Saharan Africa is urbanizing rapidly, and it is important that local governments integrate this factor into their development plans, define national urban policies that can be transformed into local initiatives aimed at combating environmental degradation, build the capacity of microfinance players to provide credit for projects aimed at preserving the environment, and promote more sustainable economic growth and poverty reduction by devoting more energy to unlocking the productivity and welfare-enhancing potential of Africa's urban areas.

5.3. Limitations and suggestion for future research

One of the limitations of this study is the inability to include all African states to easily generalise the results of this study. Indeed, the study only covers 21 of the 54 countries in Sub-Saharan Africa. This is due to difficulties to obtain data on the variables for all countries. This limitation of data also explains the choice of the analysis period. It comes as no surprise that the lack of data is one of the major handicaps that hampers empirical research in many developing regions. Also, the paper does not incorporate other elements that could explain poor environmental quality such as forest destruction and emission of other greenhouse gases, it considers only one proxy for financial development. These missing elements could be the subject of future research.

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