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The Role of Institutional Governance in Controlling Sulfur and Carbon Emissions in Africa: The Analysis of Environmental Kuznets Curve

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Authors' Note

This working paper is a product of staff members of the Strategic Research Area for Sustainable Development in East Asia (SRASDEA), which is a part of the Strategic Research Areas of Saitama University (SU), Japan. The SRASDEA aims to promote research and communication with society on issues related to sustainable development in East Asia by interdisciplinary approaches covering humanities and social sciences as well as science, technology and engineering.

This paper is an output of the SRASDEA joint research project of SU's Graduate School of Humanities and Social Sciences (Taguchi and Ni Lar) and Graduate School of Science and Engineering (Fujino). The focus of this paper is the role of institutional governance in controlling sulfur and carbon emissions in Africa. This paper aims to apply lessons learned from East Asia's experience regarding the importance of the institutional framework for environmental protection, as discussed in the existing works of the SRASDEA below.

Taguchi, H., Fujino, T., Asada, H., & Ma, J.-J. (2023). Water Pollution and Pollution–Control Capacity in Chinese Provinces: Panel Estimations of Provincial Environmental Kuznets Curves. *Sustainability,* 15(5), 3979. https://doi.org/10.3390/su15053979: and

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The Role of Institutional Governance in Controlling Sulfur and Carbon Emissions in Africa: The Analysis of Environmental Kuznets Curve

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Abstract

This study, focusing on sulfur (SO_2) and carbon (CO_2) emissions across 54 African countries, aims to investigate the validity of the inverted-U shaped environmental Kuznets curve (EKC) hypothesis and the revised EKC hypothesis representing latecomer advantages, and to demonstrate quantitative contributions of institutional governance to the mitigation of country-specific emissions in African latecomer countries. The main findings of the empirical analyses are summarized as follows. First, a distinct contrast exists in the EKC estimations between SO_2 and CO_2 emissions: the inverted-U shaped EKC and the revised EKC hypotheses are verified in SO_2 emissions, however this is not the case for CO_2 emissions. Second, focusing on SO_2 emissions, the fixed model estimation identified the significant mitigation of the country-specific emissions across 47 African latecomer countries, while the alternative model estimation revealed that institutional governance, as measured by government effectiveness, significantly diminished the emissions. Third, the factor analysis demonstrated that enhanced government effectiveness contributes to the mitigation of country-specific SO_2 emissions by almost 40%.

Keywords: sulfur and carbon emissions; Africa; environmental Kuznets curve, latecomer advantages, institutional governance

JEL Classification Codes: Q53, Q56.

1. Introduction

Reconciling economic development with environmental preservation is a crucial challenge in achieving the Sustainable Development Goals established by the United Nations during its summit in 2015. Sustainable development is particularly crucial for developing countries as they are anticipated to promote economic growth while ensuring environmental protection. In this context, African economies, as components of the global developing regions, are at a critical crossroads. They hold considerable potential for economic advancement, as most are still classified as middle-income and low-income by the World Bank's income classification[1]. A significant increase in industry has been noted throughout the continent (Chitonge 2023). Nonetheless, industrialization has resulted in environmental repercussions, and pollution challenges have intensified throughout Africa (Afriyie et al. 2023, Appiah et al. 2021). To mitigate pollution resulting from industrialization, effective institutional governance is essential (Fosu et al. 2025, Asiedu et al. 2019), however Africa generally exhibits inadequate institutional governance (Ogundele and Nzama-Sithole 2026).

Environmental issues are often studied using the analytical framework of the environmental Kuznets curve (EKC). The EKC postulates an inverted-U relationship between pollution and economic development; at early stages of development, environmental quality deteriorates as per capita income increases, while at higher levels of development, environmental degradation is seen to decrease as per capita income increases further. EKC analyses conducted to date have concentrated on the EKC modalities depending on targeted areas and pollutants, and there have been few empirical studies explicitly uncovering the nexus between pollution levels and institutional governance in the EKC frameworks. Thus, the motivation for this study is to fill this gap in the research on EKC-governance links.

This study, focusing on SO_2 and CO_2 emissions across 54 African countries, aims to investigate the validity of the inverted-U shape EKC hypothesis, and to demonstrate quantitative contributions of institutional governance to the mitigation of country-specific air pollutant emissions in African latecomer countries. This study undertakes the following procedures to accomplish these objectives. First, the EKC is estimated econometrically using a fixed-effect model, based on country-level panel data. Second, the alternative EKC is re-estimated by substituting the fixed effects with an institutional governance measure. Third, the country-specific pollution effects independent of

[1] See the website: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

country's income level are derived from the fixed effects, and the contributions of institutional governance effects to the country-specific pollution levels are quantified through a factor analysis. The main finding of this study is that the effect of government effectiveness contributes to roughly 40% of the enhancement in country-specific SO_2 emissions. Consequently, African countries possess the capability to alleviate air pollution by enhancing government effectiveness.

The subsequent sections of this work are structured as follows. Section 2 examines the literature pertinent to the EKC, encompassing EKC research in Africa, and elucidates the contributions of this work. Section 3 delineates the materials and methodologies employed in the empirical investigation. Section 4 delineates and analyzes the estimation outcomes. Ultimately, Section 5 summarizes and concludes the work.

2. Literature Review and Contributions

This section reviews the literature related to EKC issues, including the EKC analyses in Africa, and clarifies the contributions of this study.

The EKC offers a systematic approach for analyzing how economies address environmental challenges. This concept suggests a nonlinear link characterized by an inverted U-shape between pollution and economic progress. Kuznets's name was attached to the curve by Grossman and Krueger (1995), who observed its similarity to the inverted U-shaped correlation Kuznets established between income disparity and development. Dasgupta et al. (2002) assert that in the EKC dynamic process, during the first stage of industrialization, pollution worsens rapidly because people are more interested in employment and income than in clean air and water, and environmental regulation is correspondingly weak. In wealthy societies, pollution diminishes along this trajectory due to the advancement of cleaner industrial sectors, heightened environmental awareness among the populace, and the increased efficacy of regulatory organizations.

Since the World Bank (1992) initially discussed EKC issues, empirical investigations and theoretical discussions have proliferated, substantiating the relevance of the EKC to specific locations and environmental challenges (e.g., Grossman and Krueger 1995, Lopez 1994, Selden and Song 1994, Stokey 1998). During the early phase until the 1990s, the majority of empirical studies concentrated on substantiating the EKC hypothesis and its prerequisites through cross-sectional data. Since the late 1990s, however, EKC studies have transitioned from cross-sectional to time-series analysis, investigating the heterogeneity of EKCs across individual economies regarding curve shapes and positions. In this context, Dasgupta et al. (2002) delineated three distinct EKC scenarios diverging from the traditional inverted-U model: the race to the bottom (pessimistic, characterized by sustained high pollution levels), new toxics (pessimistic, featuring an elevated curve due to the emergence of novel pollutants), and the revised EKC (optimistic, exhibiting a lower and flatter curve attributed to improved pollution management). These scenarios have undergone empirical assessments (e.g., Dinda 2004, Mukhopadhyay and Chakraborty 2005, Taguchi 2012, Taguchi and Murofushi 2010). Sarkodie and Strezov (2019) conducted a thorough assessment of the variability of EKC modalities regarding their shapes and placements.

Certain studies have associated EKC placements with institutional governance, positing that institutional governance influences environmental quality. Wu (2017) performed an EKC analysis of fine particulate matter (PM2.5) incorporating governance indicators across 167 countries, proposing that countries enhancing their institutional quality implement effective air pollution controls via improved audits, refined processes, and more stringent punitive measures. Azam et al. (2021) revealed that institutional quality positively influences many environmental indicators, including CO_2 emissions, CH4 (methane) emissions, and forest areas across 66 developing nations. Danish and Ulucak (2020), together with Alharthi et al. (2025), demonstrated that enhanced institutional quality facilitates a reduction in CO_2 emissions in 18 Asia-Pacific Economic Cooperation (APEC) countries and in 33 of the most polluted countries, respectively.

A substantial amount of work investigates the EKC across global regions, particular countries, and various levels of environmental quality. Nonetheless, the quantity of empirical investigations concerning the EKC focused on Africa is rather scarce (Table 1). The EKC analyses concerning CO_2 emissions yield ambiguous and mixed results in the literature: some studies affirm the validity of the inverted U-shaped EKC (e.g., Fosu et al. 2025, Manu and Asongu 2025, Nkwatoh 2022), while others contest its validity (e.g., Achuo and Ojong 2024, Baidoo 2023, Boukhelkhal 2022, Effiong and Iriabije 2018, Jebli et al. 2015, Ogundipe et al. 2014). Other environmental indicators (Greenhouse Gas, Particulate Matter, Organic Water) possess limited evidence about the validity of the inverted U-shaped EKC, as indicated by several research (e.g., Ogundipe et al. 2017, Orubu and Omotor 2011). Regarding the EKC studies incorporating institutional governance focused on Africa, Fosu et al. (2025) revealed the crucial role of governance quality in moderating the relationship between industrialization and environmental quality: introduction of governance quality mitigated the negative environmental impact of industrialization.

This study offers multiple contributions to the existing literature. First, this study could the evidence in the literature on African EKC analysis, where findings on CO_2

emissions are equivocal and other indicators lack substantial outcomes. This study examines SO_2 and CO_2, specifically two representative indicators of air pollution. SO_2 signifies a local pollutant whose impact is not easily externalized, whereas CO_2 denotes a global pollutant whose impacts are readily externalizable. The inverted U-shaped EKC is more applicable to a local pollutant than to a global pollutant (e.g., Dinda 2004, Nahman and Antrobus 2005). Consequently, examining two pollutants (SO_2 and CO_2) and contrasting their effects would yield profound insights into the restricted assessments of the EKC in Africa. Second, this study clarifies the quantitative relationship between EKC locations and institutional governance. Previous studies have shown that improving institutional qualities results in superior environmental performance within the EKC framework; nevertheless, there is a paucity of studies quantifying the contributions of institutional governance to country-specific pollution reduction. This study addresses this research gap.

3. Empirical Analyses

This section delineates empirical analyses comprising a) a succinct overview of the correlation between per capita real GDP and environmental indices (SO_2 and CO_2 emissions), concentrating on selected African economies, b) econometric estimations to investigate the African EKC pattern, c) a factor analysis of the variability in country-specific air pollutions in relation to the institutional governance of the countries. This section commences with descriptions of data utilization.

3.1 Data

The sample comprises 54 countries across the entirety of Africa. Their profile is presented in Table 2. The population ranges from 223.151 million in Nigeria to 0.126 million in Seychelles, while per capita GDP (adjusted to 2020 constant prices) spans from 12,486 USD in Seychelles to 0.272 USD in Burundi. The per capita pollution levels (SO_2 and CO_2) vary in accordance with population size and per capita GDP. The period for the sample extends from 2002 to 2022, dependent on the availability of a governance indicator. Consequently, we assemble a panel data set that includes 54 countries during the period from 2002 to 2022 (54 x 21 = 1,134).

The variables along with their data origins for the forthcoming estimations are enumerated in Table 3, and their descriptive statistics are presented in Table 4. Concerning the air pollution indices, the per capita emissions of SO_2 (so2) and CO_2 (co2), measured in kilograms per individual, are sourced from the Our World in Data dataset[2]. The per capita GDP (pcy) data, expressed in 2020 constant prices, is sourced from UNCTAD stat[3] and converted into logarithmic form to mitigate scaling issues in the estimation. The latecomers' index (lca) represents the extent of delayed development, specifically the ratio of a country's per capita GDP to that of the benchmark country (South Africa) in a given year[4]: a lower lca signifies a more delayed stage of development of the country. Regarding the institutional governance metric, the "government effectiveness" index (gve) is derived from the World Governance Indicators[5]. Government effectiveness evaluates the caliber of public services, the civil service, the formulation and execution of policies, and the dedication of the government to enforcing these policies. Consequently, air quality regulations can gain from a significant degree of government effectiveness.

In the ensuing panel estimation, we investigate the stationary property of the constructed panel data by employing the following panel unit root tests: the Levin, Lin, and Chu test (Levin et al., 2002) as a common unit root test, and the Fisher-ADF and Fisher-PP tests (Choi, 2001; Maddala and Wu, 1999) as individual unit root tests. The common unit root test assumes that there is a common unit root process across cross-sections, whereas the individual unit root test allows for individual unit root processes that vary across cross sections. These tests are performed on the assumption of the null hypothesis that a level of panel data possesses a unit root by incorporating “intercept” and “intercept and trend” within the testing equations. Table 5 indicates that the outcomes of the Levin, Lin, and Chu test reject the null hypothesis of a unit root at the conventional significance level for all variables. The individual unit root tests do not uniformly dismiss the null hypothesis; still, the Fisher-PP test consistently rejects the null hypothesis at the conventional level for all variables. Therefore, the study presumes that there are no serious problems with unit roots in the panel data, permitting the utilization of the panel data in levels for subsequent estimations.

3.2 Overview of African EKCs

This section succinctly overviews the relationship between GDP per capita

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[2] See the website: https://ourworldindata.org/.
[3] See the website: https://unctadstat.unctad.org/datacentre/.
[4] South Africa is chosen as a benchmark in computing the latecomers’ index; However, the choice of benchmark country does not affect the estimation result (only affects the size of the latecomers’ index and its coefficient), just because the benchmark is, once decided, commonly used in computing the latecomers’ index of each country.
[5] See the website: https://www.worldbank.org/en/publication/worldwide-governance-indicators.

(horizontal axis) and per capita emissions of SO_2 and CO_2 (vertical axis) for the years 2002-2022 in certain African countries (Figure 1). Out of 54 sample countries, we identify the 11 countries that represent each category in the World Bank's income classification: Burundi, Eritrea, and Niger in low-income bracket; Djibouti, Egypt, Lesotho, Morocco, Sao Tome and Principe, Senegal, and Tunisia in the lower middle-income tier; and Algeria in the upper middle-income category.

The preliminary observation indicates a disparity in the form of the trajectories of the curves. The figure for SO2 emissions exhibits an inverted-U shape, while the one for CO_2 emissions indicates a rising trend. The variation in the per capita GDP-emissions correlation regarding its form may provide different implications for SO_2 and CO_2 emissions. This aspect is empirically examined via an econometric analysis in the subsequent section.

3.3 Econometric Estimations

This section conducts econometric analyses to examine the African EKC pattern, encompassing methodology, findings and discussions.

3.3.1 Methodology: Model Specification

This study predominantly adheres to the conventional structure of the EKC: the typical nonlinear model, where per capita air pollution is regressed against per capita income and its square, using the latecomers' index as an additional regressor. The initial specification in Equation (1) employs a fixed-effect model for dynamic panel data estimation to clearly illustrate the pollution effects specific to each country, while the alternative models in Equation (2) substitute the fixed effects with an institutional governance indicator to clarify the contribution of institutional governance on country-specific pollution levels. The formulas employed for the calculations are as follows:

$$(so2_{it}, co2_{it}) = \alpha_0 + \alpha_1 (so2_{it-1}, co2_{it-1}) + \alpha_2 \ln pcy_{it} + \alpha_3 (\ln pcy_{it})^2 + \alpha_4 \, lca + f_i + \varepsilon_t \qquad (1)$$

$$(so2_{it}, co2_{it}) = \beta_0 + \beta_1 (so2_{it-1}, co2_{it-1}) + \beta_2 \ln pcy_{it} + \beta_3 (\ln pcy_{it})^2 + \beta_4 \, gve + \varepsilon_t \qquad (2)$$

where the subscripts i and t denote a sample of 54 African countries and the years 2002–2022, respectively. The variables named so2, co2, pcy, lca, and gve, together with their data sources are described in Section 3.1 and Table 3. f_i shows a time-invariant country-specific fixed effect; ε denotes a residual error term; $\alpha_{0 \ldots 4}$, and $\beta_{0 \ldots 4}$ represent estimated coefficients; and “ln” shows a logarithm form.

Clarifications on the specifications of the estimating models in Equations (1) and (2) are necessary for further elaboration. Initially, the model specification employs a dynamic panel model, incorporating a lagged dependent variable, ($so2_{it-1}$, $co2_{it-1}$), as an independent variable. Halkos (2003) indicated that employing a static model is defensible solely when the processes are exceedingly swift or when the static equation depicts an equilibrium relationship. Given that neither swift modifications nor an equilibrium correlation between pollution and income were anticipated, a dynamic modeling technique would yield more statistically robust estimates. Consequently, Equations (1) and (2) use a lagged dependent variable as a predictor to provide a gradual adjustment towards an equilibrium emissions level. The dynamic panel estimation that incorporates the lagged dependent variable as one of the explanatory variables necessitates the utilization of the Generalized Method of Moments (GMM), as established by Arellano and Bond (1991), to obtain consistent estimations. The GMM estimator eliminates country effects by first-differencing as well as controls for possible endogeneity of explanatory variables. The Sargan test for over-identifying restrictions is performed throughout the estimations. The use of a dynamic panel model is validated when the coefficients of α_1 and β_1 in Equations (1) and (2) are significantly positive.

Second, the incorporation of the latecomers' index (lca) in Equation (1) serves to ascertain the presence of one of the EKC scenarios posited by Dasgupta et al. (2002), specifically, the revised EKC scenario (a lower and flatter EKC for latecomers attributed to their improved pollution management). In the revised EKC scenario, latecomer countries benefit from latecomer advantages, enabling them to achieve superior environmental performances through technological transfers from forerunner countries (Schneider et al. 2024). In such a scenario, latecomer countries may exhibit lower per capita pollutant emissions than forerunner countries at the same income levels: the EKCs of latecomers could be positioned below those of forerunners. Thus, in the revised EKC scenario, the coefficient of lca (α_4) in Equation (1) is supposed to be significantly positive: a lower latecomers’ index indicative of delayed development correlates with lower per capita emissions.

The last point concerns expected the significances and signs of the other coefficients in Equations (1) and (2). To verify the inverted-U shape of EKCs, one should examine the signs of α_2, α_3, β_2, and β_3. The per capita emissions might be considered to demonstrate a meaningful EKC in relation to per capita GDP, provided that $\alpha_2 > 0$, $\alpha_3 < 0$, and $\beta_2 > 0$, $\beta_3 < 0$. The fixed-effect denoted by f_i in Equation (1) signifies a country-specific pollution effect independent of country’s income level. Its effect encompasses any elements of unobserved time-invariant heterogeneities among the sample countries so that incorporating its effect helps alleviate the endogeneity problem in the estimation. This study designates South Africa and the countries with a per capita GDP exceeding that of South Africa in 2022 (Botswana, Gabon, Libya, Mauritius, and Seychelles) as benchmark countries. Consequently, the exhibited fixed effect signifies the country-specific pollution effect of latecomer countries in comparison to the benchmark countries. If the latecomer countries benefit from latecomer advantages in terms of lower per capita pollution emissions, their fixed effects are supposed to be significantly negative. In the alternative model of Equation (2), the pivotal coefficient is β_4, the one of government effectiveness (gve). If enhanced government effectiveness is workable enough to mitigate per capita emissions via robust air quality management, the coefficient is expected to be significantly negative.

3.3.2 Results and Discussions

Table 6 shows the results of dynamic panel estimations of Equations (1) and (2) on SO_2 and CO_2 emissions. The coefficients of lagged dependent variables are significantly positive, and the Sargan tests do not suggest rejection of the instrumental validity, except for the case of CO_2 emissions in Equation (1). Thus, the adoption of dynamic panel estimations is justified at least for the case of SO_2 emissions.

The inverted-U shapes of EKCs are identified in SO_2 emissions, not in CO_2 emissions: the coefficients, $\alpha_2 > 0$, $\alpha_3 < 0$, and $\beta_2 > 0$, $\beta_3 < 0$ are significantly confirmed in Equations (1) and (2) only in SO_2 emissions. The revised EKC scenario representing latecomer advantages is verified in SO_2 emissions, not in CO_2 emissions: the coefficient of lca is significantly positive in Equation (1) solely in SO_2 emissions. The contrasts in estimation outcomes above between SO_2 and CO_2 may stem from the distinct characteristics of pollutants: SO_2 signifies a local pollutant whose impact is not easily externalized, whereas CO_2 denotes a global pollutant whose impacts are readily externalizable. Dinda (2004) and Nahman and Antrobus (2005) contend that EKCs are more likely to hold for local pollutants and not hold for global pollutants: local pollutants are subject to regulation, whereas global pollutants are easily externalized and thus not subject to regulation. Local pollutants also allow latecomer countries to adhere to the revised EKC scenario, reaping benefits from latecomer advantages, via the transfers of emission-control technologies and policy expertise from forerunner countries. In fact, the pollution controls on SO_2 have been promoted intensively over a broad area of Asia since the 1970s. Iwami (2001) argues that the remarkable reduction in sulphur emissions in

Japan from the early 1970s to the mid-1980s was a result of stringent environmental regulations enforced by both central and local authorities, and technological development for desulphurization and energy efficiency driven by private companies; furthermore, it notes that other East and South-East Asian countries implemented the initiatives of environmental management in their early stage of development by acquiring emission-control technologies and policy expertise from developed nations, including Japan.

Now that the revised EKC scenario is identified in the case of SO_2 (not CO_2) emissions, the subsequent analyses focus on SO_2 emissions and investigate the relationship between fixed effects of individual latecomer countries (the country-specific emission effect) and the contributions of institutional governance (government effectiveness). The fixed effects of individual latecomer countries are presented in Column (a) of Table 7. The coefficients are negative except Namibia, and most of them are significant at conventional levels. It suggests that the country-specific emission levels of latecomer countries are lower than those of benchmark countries, implying that latecomer countries gain latecomer advantages. The degree of less emissions is indicated by the magnitude of the coefficients of the country-fixed effects. For example, that of SO_2 in Algeria (column (a) in Table 7) is exp. (-0.939), which is around 60% less than those in benchmark countries. The coefficient of government effectiveness in the alternative model of Equation (2) is significantly negative, suggesting the effectiveness of government roles to mitigate the emissions. The joint estimation outcomes of country-specific pollution effects and the workability of government effectiveness prompt inquiries regarding the quantitative contributions of government effectiveness to the mitigation of country-specific emissions.

3.4 Factor Analysis on Government Effectiveness

Table 7 displays the result of the factor analysis regarding government effectiveness in relation the mitigation of country-specific SO_2 emissions. Column(a) illustrates the fixed effect of latecomer countries in the estimation of Equation (1) in Section 3.3.2.; column (b) presents the average value over the period of the government effectiveness indicator (gve); column (c) computes the contributions of government effectiveness by multiplying the value in column (b) by the estimated coefficient of government effectiveness (gve), -0.008, found in Table 6; and column (d) demonstrates the contribution ratio of government effectiveness to the fixed effect by dividing column (c) by column (a). The last row of column (d) indicates the mean contribution ratio for latecomer countries, which is 0.378.

In summary, the factor analysis revealed that institutional governance measured by government effectiveness contributes to the mitigation of country-specific SO_2 emissions in African latecomer countries by almost 40%. This finding aligns with the works of Fosu et al. (2025), Wu (2017), Azam et al. (2021), Danish and Ulucak (2020), and Alharthi et al. (2025), which demonstrate the role of institutions in environmental performances. The finding of the factor analysis is also consistent with the assertions of Schneider et al. 2024, and Frikha and Gabsi (2026), who contended that institutional qualities facilitate the acquisition of technological transfers for latecomer countries. However, this study, unlike previous policy studies, explicitly and quantitatively demonstrates the effects of institutional governance on air pollution.

4. Concluding Remarks

This study, focusing on SO_2 and CO_2 emissions across 54 African countries, investigated the validity of the inverted-U shape EKC hypothesis and the revised EKC hypothesis representing latecomer advantages, and demonstrated quantitative contributions of institutional governance to the mitigation of country-specific SO_2 emissions in African latecomer countries. This study employed a dynamic panel fixed model utilizing the GMM estimator for the EKC estimation and performed a factor analysis for computing the contributions of institutional governance. The main findings of the empirical analyses are summarized as follows. First, a distinct contrast exists in the EKC estimations between SO_2 and CO_2 emissions: the inverted-U shaped EKC and the revised EKC hypotheses are verified in SO_2 emissions, however this is not the case for CO_2 emissions. Second, focusing on SO_2 emissions, the fixed model estimation identified the significant mitigation of the country-specific emissions across 47 African latecomer countries, while the alternative model estimation revealed that institutional governance, as measured by government effectiveness, significantly diminished the emissions. Third, the factor analysis demonstrated that government effectiveness contributes to the mitigation of country-specific SO_2 emissions by almost 40%.

The policy implication of this study is that African countries possess considerable policy space to address air pollutions through improved institutional governance for pollution control. The limitation of this study encompasses an absence of detailed analysis on individual countries. Africa exhibits regional heterogeneity in terms of pollution levels and the factors affecting them. Examining the complexity of pollution mechanisms and policy performance in specific countries via detailed case studies would facilitate the formulation of tailored recommendations for air pollution management in Africa.

References

Achuo, E., and Ojong, N. 2024. Foreign direct investment, economic growth and environmental quality in Africa: revisiting the pollution haven and environmental Kuznets curve hypotheses. *Journal of Economic Studies*, 52(4): 673-691.

Afriyie, D., Wang, Z., Hu, S., Ampofo, G.K.M. and Asante, D.A. 2023 Exploring the dynamic nexus between urbanization and industrialization with carbon emissions in sub-Saharan Africa: evidence from panel PMG-ARDL estimation. *Environmental Science and Pollution Research*, 30(3): 6373–6389.

Alharthi, M., Hassan, M.S., Huang, J., Mahmood, H., and Arshad, H. 2025. Institutional quality and environmental sustainability nexus: Fresh evidence of most polluted countries in a CS–ARDL framework. *Natural Resources Forum*, 49(2): 2048-2066.

Appiah, M., Li, F. and Korankye, B. 2021. Modeling the linkages among CO 2 emission, energy consumption, and industrialization in sub-Saharan African (SSA) countries. *Environmental Science and Pollution Research*, 28: 38506–38521.

Arellano, M., and Bond, S.R. 1991. Some tests of specification of panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies*, 58: 277-297.

Asiedu, E., Atici, C. and Dogo, H. 2019. Governance, foreign direct investment, and environmental sustainability in sub-Saharan Africa. *Environmental Science and Pollution Research*, 26(17): 17148–17163.

Azam, M., Liu, L., and Ahmad, N. 2021. Impact of institutional quality on environment and energy consumption: evidence from developing world. *Environment, Development and Sustainability: A Multidisciplinary Approach to the Theory and Practice of Sustainable Development*, 23(2): 1646-1667.

Baidoo, D.A. 2023. Does the Validity of the Environmental Kuznets Curve Postulation Empirically Depend on the Level of Human Development in Africa? *American Journal of Environment Studies*, 6(2): 64-92.

Boukhelkhal, A. 2022. Energy use, economic growth and CO2 emissions in Africa: does the environmental Kuznets curve hypothesis exist? New evidence from heterogeneous panel under cross-sectional dependence. *Environment, Development and Sustainability: A Multidisciplinary Approach to the Theory and Practice of Sustainable Development*, 24(11): 13083-13110.

Chitonge, H. 2023. Murmurs of an industrial revolution in Africa: is it time for Africa?, in *Handbook of Industrial Development*, 54–74, Edward Elgar Publishing: Cape Town.

Choi, I, 2001. Unit root tests for panel data. *Journal of International Money and Finance*, 20(2): 249-272.

Danish, and Ulucak, R. 2020. The pathway toward pollution mitigation: Does institutional quality make a difference? *Business Strategy and the Environment*, 29(8): 3571-3583.

Dasgupta, S., Laplante, B., Wang, H., and Wheeler, D. 2002. Confronting the Environmental Kuznets Curve. *Journal of Economics Perspectives*, 16(1): 147-168.

Dinda, S. 2004. Environmental Kuznets Curve hypothesis: a survey. *Ecological Economics*, 49: 431-455.

Effiong, E.L., and Iriabije, A.O. 2018. Let the data speak: semiparametric evidence on the environmental Kuznets curve in Africa. *Quality & Quantity: International Journal of Methodology*, 52(2): 771-782.

Fosu, R.A., Yiadom, E.B., Acheampong, E. and Obeng, K. 2025. Industrialisation and environmental quality in Africa: governance and industrial Kuznets curve perspective in quantile and threshold analysis. *International Journal of Green Economics*, 19(1): pp.21–43.

Frikha, N., and Gabsi, F.B. 2026. Green technologies and inclusive growth in Sub-Saharan Africa: transmission channels. *International Journal of Energy and Water Resources*, 10:78.

Grossman, G. and Krueger, A. 1995. Economic growth and the environment. *The Quarterly Journal of Economics*, 112: 353-378.

Halkos, G.E. 2003. Environmental Kuznets Curve for sulphur: evidence using GMM estimation and random coefficient panel data models. *Environment and Development Economics*, 8(4): 581-601.

Iwami, T. 2001. Advantage of latecomer in abating air-pollution: experience in East Asia. *CIRJE-J-64, Discussion Paper Series*, Faculty of Economics, University of Tokyo.

Jebli, M.B., Youssef, S.B., and Ozturk, I. 2015. The Role of Renewable Energy Consumption and Trade: Environmental Kuznets Curve Analysis for Sub-Saharan Africa Countries. *African Development Review*, 27(3): 288-300.

Orubu, C.O., and Omotor, D.G. 2011. Environmental quality and economic growth: Searching for environmental Kuznets curves for air and water pollutants in Africa. *Energy Policy*, 39(7): 4178-4188.

Levin, A,, Lin, C.F., and Chu, C.S.J. 2002. Unit root tests in panel data: Asymptotic and finite-sample properties. *Journal of Econometrics*, 108(1): 1-24.

Lopez, R. 1994 The environment as a factor of production: the effects of economic growth and trade liberalization, *Journal of Environmental Economics and Management*, 27(2): 163-184.

Maddala, G.S., and Wu, S. 1999. A comparative study of unit root tests with panel data and a new simple test. *Oxford Bulletin of Economics and Statistics*, 61(S1): 631-652.

Manu, E.K., and Asongu, S.A. 2025. Renewable energy, innovations and environmental sustainability in Sub-Saharan Africa: The Environmental Kuznets Curve, policy thresholds and thresholds for complementary policies. *Renewable Energy*, 249(C).

Mukhopadhyay, K., and Chakraborty, D. 2005. Is liberalization of trade good for the environment? Evidence from India. *Asia-Pacific Development Journal*, 12(1): 109-136.

Nahman, A., and Antrobus, G. 2005. The Environmental Kuznets Curve: a literature survey. *South African Journal of Economics*, 73(1): 105-120.

Nkwatoh, L.S. 2022. Zero-pollution effect and economic development: standard and nested environmental Kuznets curve analyses for West Africa. *Environment, Development and Sustainability: A Multidisciplinary Approach to the Theory and Practice of Sustainable Development*, 24(10): 11895-11910.

Ogundele, O.S., and Nzama-Sithole, L. 2026. Institutional Quality and Its Implications for Corporate Sustainability and Sustainable Development Goals in Selected African Countries. In: Kumar, K., Bhaskar, P., Yıldırım, S., Nandy, M. (eds), *Sustainable Value Creation*: *Corporate Strategies for SDGs Implementation*. World.

Ogundipe, A.A., Alege, P.O., and Ogundipe, O.M. 2014. Income Heterogeneity and Environmental Kuznets Curve in Africa. *Journal of Sustainable Development*, 7(4): 165-165.

Ogundari, K., Ademuwagun, A.A., and Ajao, O.A. 2017. Revisiting Environmental Kuznets Curve in Sub-Sahara Africa. *International Journal of Social Economics*, 44(2): 222-231.

Sarkodie, S.A., and Strezov, V. 2019. A review on Environmental Kuznets Curve hypothesis using bibliometric and meta-analysis. *Science of The Total Environment*, 649: 128-145.

Selden, T.M., and Song, D. 1994. Environmental quality and development: is there a Kuznets Curve for air pollution emissions? *Journal of Environmental Economics and Management*, 27: 147-162.

Schneider, C.P., Guenther, E., and Most, D. 2024. International technology transfer to Africa in light of the SDGs: What do we know about the barriers? *Journal of International Development*, 36(4): 2129-2151.

Stokey, N.L. 1998. Are there limits to growth? *International Economic Review*, 39: 1-31.

Taguchi, H., and Murofushi, H. 2010. Evidence on the interjurisdictional competition for polluted industries within China. *Environment and Development Economics*, 15(3): 363-378.

Taguchi, H. 2012. Environmental Kuznets Curve in Asia: The case of SO2 and CO2 emissions. *Asia-Pacific Development Journal*, 19(2): 77-92.

World Bank 1992. *Development and the Environment, World Development Report*. Oxford University Press, Washington, DC.

Wu, W.L. 2017. Institutional Quality and Air Pollution: International Evidence. *International Journal of Business and Economics*, 16(1): 49-74.

Table 1 Literature review of the EKC in Africa

	Sample Areas	Pollutants	EKC Hypo.	Notes
Achuo & Ojong (2024)	46 countries Africa	CO_2	No	N-shaped EKC Environmental impacts of FDI infolws
Baidoo (2023)	50 countries Africa	CO_2	No	Valid EKC only in high HDI countries
Boukhelkhal (2022)	35 countries Africa	CO_2	No	Non-renewable energy effect
Effiong & Iriabije (2018)	49 countries Africa	CO_2, PM_{10}	No	
Jebli et al (2015)	24 countries Sub-Saharan Africa	CO_2	No	Impacts of exports and imports
Ogundipe et al (2014)	53 countries Africa	CO_2	No	Valid EKC only in lower middle incomers
Fosu et al (2025)	44 countries Africa	CO_2	Yes	Governance quality's influence
Manu & Asongu (2025)	24 countries Sub-Saharan Africa	CO_2, Methane	Yes	Effects of renewable energy and innovation
Nkwatoh (2022)	West Africa	CO_2	Yes	Technology-CO_2 relationship
Ogundipe et al (2017)	43 countries Sub-Saharan Africa	GHG from Agric.	Yes	
Orubu & Omotor (2011)	Africa	Suspended PM Organic Water	Yes	Suspended PM

Sources: Authors' description

Table 2 Profile of Sample Countries in Africa (2022)

	Population thou. Persons	GDP per capita 2020 const. prices	SO_2 per capta kilograms	CO_2 per capta kilograms
Algeria	45,477	3,900	1.216	4.239
Angola	35,635	1,986	2.461	0.592
Benin	13,760	1,298	0.682	0.443
Botswana	2,440	7,224	16.175	3.031
Burkina Faso	22,509	855	0.808	0.291
Burundi	13,321	272	0.223	0.066
Cabo Verde	520	4,346	7.241	1.150
Cameroon	27,633	1,582	1.012	0.354
Central African Rep.	5,098	463	0.567	0.074
Chad	18,455	845	0.184	0.152
Comoros	834	1,551	1.638	0.637
Congo	6,035	1,762	1.470	1.446
Cote d'Ivoire	30,395	2,362	0.537	0.477
Dem. Rep. of the Congo	102,397	526	0.192	0.058
Djibouti	1,137	3,036	3.797	0.484
Egypt	112,618	3,818	5.001	2.219
Equatorial Guinea	1,804	5,739	2.499	4.157
Eritrea	3,409	654	1.907	0.211
Eswatini	1,219	3,536	4.252	0.844
Ethiopia	125,384	857	0.430	0.135
Gabon	2,431	6,599	2.804	2.379
Gambia	2,636	763	1.304	0.306
Ghana	33,149	2,305	1.201	0.626
Guinea	14,055	2,200	1.558	0.288
Guinea-Bissau	2,106	737	1.023	0.164
Kenya	54,252	2,093	0.885	0.379
Lesotho	2,286	941	7.122	1.116
Liberia	5,373	677	1.368	0.161
Libya	7,224	7,315	13.275	8.164
Madagascar	30,437	467	1.310	0.138
Malawi	20,569	604	0.518	0.088
Mali	23,073	957	0.527	0.304
Mauritania	4,876	1,823	3.289	1.080
Mauritius	1,276	10,047	36.551	3.383
Morocco	37,329	3,580	3.098	1.869
Mozambique	32,656	466	0.979	0.285
Namibia	2,890	3,999	40.201	1.181
Niger	25,312	592	0.376	0.126
Nigeria	223,151	2,814	0.534	0.589
Rwanda	13,651	915	0.473	0.143
Sao Tome and Principe	226	2,141	3.719	0.599
Senegal	17,651	1,757	4.661	0.801
Seychelles	126	12,483	41.439	5.010
Sierra Leone	8,277	901	0.796	0.174
Somalia	17,802	515	0.343	0.071
South Africa	62,378	5,798	45.339	6.874
South Sudan	11,021	353	0.509	0.148
Sudan	49,383	805	0.751	0.355
Togo	9,090	916	0.674	0.339
Tunisia	12,119	3,777	3.544	2.540
Uganda	47,313	900	0.317	0.130
United Rep. of Tanzania	64,712	1,106	0.358	0.304
Zambia	20,153	1,006	11.907	0.543
Zimbabwe	16,069	2,418	3.219	0.761

Sources: Authors' description

Table 3 List of Variables and Data Sources

Variables	Description	Sources
Dependent Variable		
so2	per capita sulfur dioxide emissions, kilograms per person	Our World in Data
co2	per capita carbon dioxide emissions, kilograms per person	
Explanatory Variables		
pcy	per capita GDP, constant prices (2020), logarithm	UNCTAD Stat
lca	latecomers' index, representing the later degree of development	Authors' Estimate
gve	government effectiveness, from 0 (weak) to 100 (strong)	WGI

Sources: Authors' description

Table 4 Descriptive Statistics

Variables	Obs.	Median	Std. Dev.	Min.	Max
Dependent Variable					
so2	1,134	1.232	15.364	0.157	113.284
co2	1,134	0.369	1.878	0.021	10.634
Explanatory Variables					
pcy	1,134	7.035	0.989	5.389	9.959
lca	1,134	0.192	0.515	0.000	3.592
gve	1,134	36.469	12.276	7.736	72.739

Sources: Authors' description

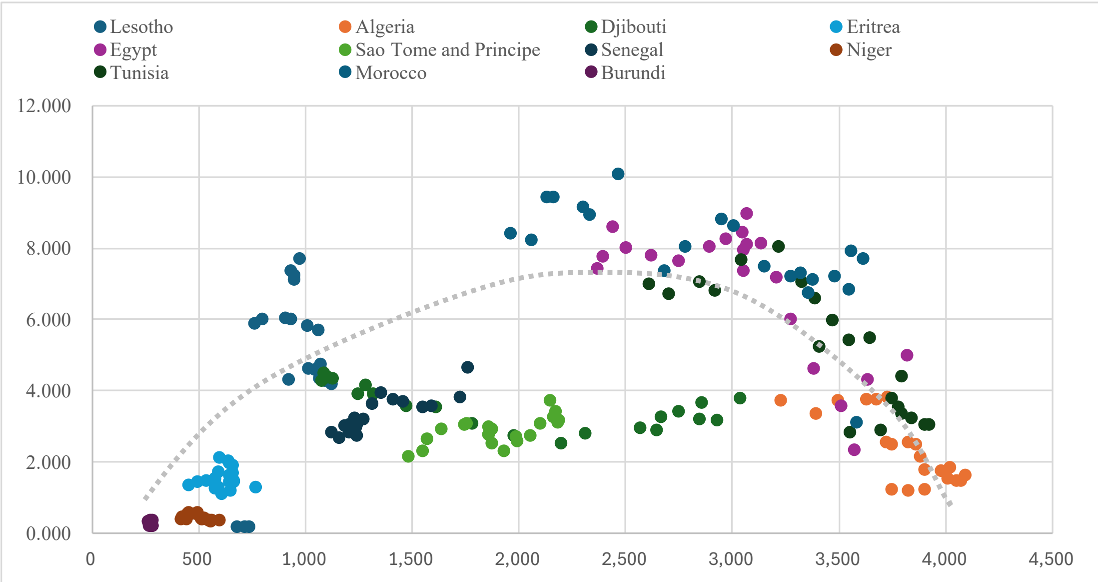
Table 5 Panel Unit Root Tests

Variables	Levin, Lin, & Chu	Fisher-ADF Chi-Square	Fisher-PP Chi-Square
so2	-6.321 ***	131.373 *	180.799 ***
co2	-9.721 ***	173.546 ***	225.978 ***
pcy	-3.950 ***	147.350 ***	413.968 ***
pcy^2	-6.843 ***	170.165 ***	197.626 ***
lca	-6.236 ***	100.446	157.680 ***
gve	-4.863 ***	209.068 ***	154.353 ***

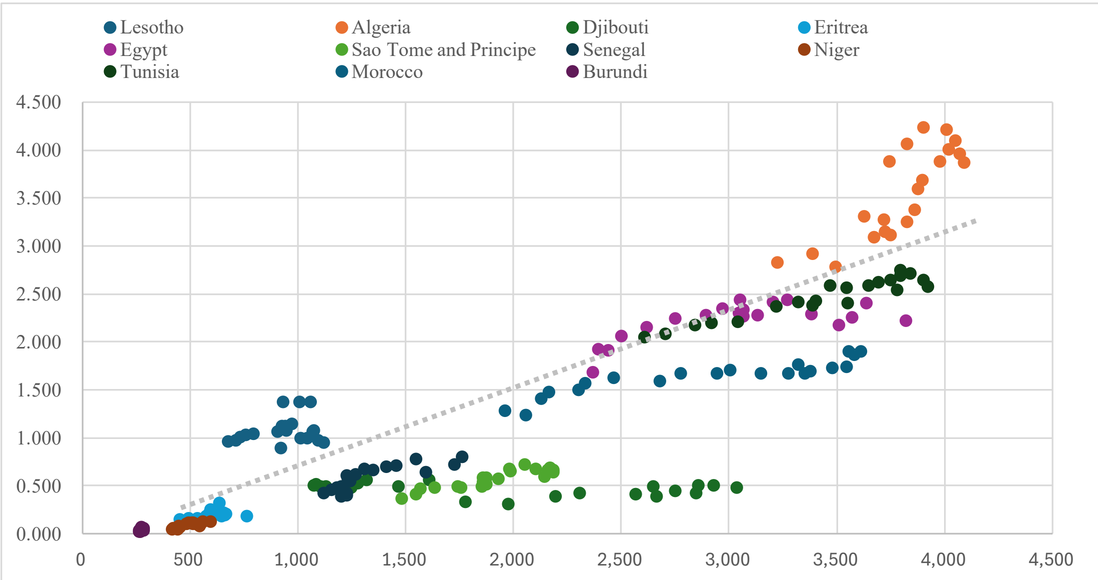
Sources: Authors' estimation

Figure 1 Relationship between GDP per capita and Emissions per capta

[Sulfur Emissions]



[Carbon Emissions]



Sources: Authors' description

Table 6 Results of Dynamic Panel Estimation by GMM

so2	(1)	(2)
pcy	33.970 *	4.709 **
	(2.217)	(2.918)
pcy^2	-2.650 **	-0.333 **
	(-2.264)	(-2.901)
lca	12.749 **	
	(2.670)	
gve		-0.008 **
		(-2.971)
so2(-1)	0.275 *	0.929 ***
	(1.823)	(11.398)
Ajusted R^2	0.960	0.948
Sargan test	0.143	0.710
Fixed Effect (corss-section)	Yes	No
Cross-sections	54	54
Periods	2002-2022	2002-2022

co2	(1)	(2)
pcy	-14.398 *	-1.986
	(-1.967)	(-0.640)
pcy^2	1.070 *	0.042
	(1.970)	(0.644)
lca	-1.829	
	(-1.343)	
gve		-0.000
		(-0.381)
co2(-1)	-0.320	0.864 ***
	(-1.168)	(4.939)
Ajusted R^2	0.986	0.973
Sargan test	0.004	0.289
Fixed Effect (corss-section)	Yes	No
Cross-sections	54	54
Periods	2002-2022	2002-2022

Notes: ***, **, * denote statistical significance at the 99%, 95%, and 90% levels, respectively. Sargan test denotes the p-value of a Sargan-Hansen test of overidentifying restrictions.
Sources: Authors' estimation

Table 7 Fixed Effects and Contribution of Government Effectiveness in Latecomers

	fixed effect	gev	(b) × -0.008	(c) / (a)
	(a)	(b)	(c)	(d)
Algeria	-0.939	40.586	-0.308	0.328
Angola	-0.658	29.520	-0.224	0.341
Benin	-0.825	42.255	-0.321	0.389
Burkina Faso	-0.835	38.100	-0.289	0.347
Burundi	-0.911	27.746	-0.211	0.231
Cabo Verde	-0.397	54.035	-0.411	1.033
Cameroon	-0.800	34.742	-0.264	0.330
Central African Rep.	-0.870	20.455	-0.155	0.179
Chad	-0.882	26.230	-0.199	0.226
Comoros	-0.762	23.152	-0.176	0.231
Congo	-0.756	29.905	-0.227	0.300
Cote d'Ivoire	-0.874	32.460	-0.247	0.282
Dem. Rep. of the Congo	-0.895	19.336	-0.147	0.164
Djibouti	-0.657	36.700	-0.279	0.424
Egypt	-0.522	42.054	-0.319	0.613
Equatorial Guinea	-1.391	27.607	-0.210	0.151
Eritrea	-0.786	27.539	-0.209	0.266
Eswatini	-0.699	41.899	-0.318	0.455
Ethiopia	-0.872	38.386	-0.292	0.334
Gambia	-0.803	39.153	-0.297	0.370
Ghana	-0.813	50.061	-0.380	0.468
Guinea	-0.770	31.942	-0.243	0.315
Guinea-Bissau	-0.822	26.853	-0.204	0.248
Kenya	-0.821	41.188	-0.313	0.381
Lesotho	-0.173	42.668	-0.324	1.869
Liberia	-0.802	26.564	-0.202	0.252
Madagascar	-0.810	36.403	-0.277	0.341
Malawi	-0.881	37.410	-0.284	0.322
Mali	-0.853	32.751	-0.249	0.292
Mauritania	-0.639	37.059	-0.282	0.440
Morocco	-0.575	46.719	-0.355	0.617
Mozambique	-0.820	38.037	-0.289	0.352
Namibia	5.668	56.181	-0.427	-
Niger	-0.878	37.445	-0.284	0.324
Nigeria	-0.882	30.893	-0.235	0.266
Rwanda	-0.871	47.489	-0.361	0.414
Sao Tome & Principe	-0.599	37.356	-0.284	0.473
Senegal	-0.546	46.602	-0.354	0.649
Sierra Leone	-0.840	27.936	-0.212	0.253
Somalia	-0.893	11.981	-0.091	0.102
South Sudan	-0.853	13.225	-0.100	0.118
Sudan	-0.811	25.220	-0.192	0.236
Togo	-0.839	26.840	-0.204	0.243
Tunisia	-0.736	54.937	-0.417	0.567
Uganda	-0.868	41.884	-0.318	0.367
United Rep. of Tanzania	-0.860	41.531	-0.316	0.367
Zambia	-1.640	37.467	-0.285	0.174
Zimbabwe	-0.684	28.242	-0.215	0.314
			Average	0.378

Sources: Authors' estimation