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Determinants of access to clean fuels and technologies for cooking in Africa: A panel autoregressive distributed lag approach

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Abstract

Clean cooking fuels and technologies remain essential in addressing the climate crises, environmental degradation, deforestation, air pollution, health complications, and poverty. Nevertheless, many countries in Africa lack access to clean fuels and technologies for cooking. The extant literature remains scarce on the determinants of clean cooking fuels and technologies using macroeconomic indicators covering many African countries in a single study. This article addresses this gap using panel data from 38 African countries. The paper shows that rural population, particulate matter emission, and natural resources depletion significantly decreased access to clean cooking fuels and technologies in the long run while the gross domestic product (GDP) per capita significantly increased access to clean cooking fuels and technologies in the long run in Africa. The results show a bi-causal relationship between clean cooking fuels and technologies and rural population, GDP per capita, natural resource depletion, and particulate emissions damage. Understanding the determinants of clean cooking fuels and technologies will expand insights into addressing challenges associated with particulate emission damages. Governments in Africa should target improvements in GDP per capita, promote advocacies, and advocate for investments to address the limited access to clean cooking fuels and technologies, particularly for the rural poor.

KEYWORDS
access to clean fuels and technologies for cooking, foreign direct investment, GDP per capita, natural resources depletion, particulate emission damage, rural population

1 | INTRODUCTION

In recent years, there have been a lot of discussions on access to clean fuels and technology.[1–3] This is in recognition of the fact that reliance on fossil fuels has environmental, health and economic consequences.[1,4–6] The global Sustainable Development Goals (SDGs), such as access to affordable, reliable, sustainable and modern energy (SDG-7), good health and well-being (SDG-3), responsible consumption and production (SDG-12) and climate action (SDG-13) are geared toward improved well-being and the reduction of carbon emissions. Access to clean cooking fuels and technologies remains an essential focus in the quest for improved human development and climate health. Most countries in Sub-Saharan Africa (SSA) heavily rely on fossil fuels, a major emitter of carbon dioxide, and greenhouse gases (GHGs).[5] Although carbon emissions in Sub-Saharan Africa (SSA) remain low relative to the global south, there has been a steady rise in carbon emissions from an estimated 9.2 to 33.8 million ktons covering the period 1960–2016.[7]

An estimated 3 billion individuals globally rely on biomass fuels for heating and cooking,[8–11] with 720 million recorded in SSA.[8,12] Approximately 600 million individuals do not have access to electricity, complemented by 900 million who cook with traditional fuels, and thus do not have access to clean fuels.[13] Forecast shows that half (50%) of the global population who will not get access to clean cooking fuels will stem from Africa.[13] Less than 20% of the SSA population has access to clean energy[1] and IEA et al.[6] reports that the majority of families in Africa without access to clean fuels and technologies are set to increase by 20 million per year this decade. These families predominantly depend on biomass fuels (firewood, dung, twigs, charcoal, and crop residues) and dirty fossil fuels[7] for cooking.

Clean fuels and technologies are stoves fueled by electricity, natural gas, biogas, liquefied petroleum gas (LPG), solar, and alcohol (e.g., ethanol).[6] Access to clean fuels and technologies remains important because aside from the environmental benefits (reduction in natural resource depletion, particulate emission damages), it directly contributes to economic growth, gender empowerment, and improved health.[14,15] Clean cooking fuels are beneficial to families as they reduce the time spent on preparing meals and also limit the risk faced by women and children in particular who bear the burden of collecting wood fuels for cooking.[5,6,16] More so, exposure to Household Air Pollution (HAP) which may ultimately result to death is minimized, and this as well improves the health of the family members, particularly women and children who are mostly directly linked with meal preparations in the home.

The myriad of benefits derived from the use of clean fuels and technologies has ultimately drawn increased global attention to investments in clean energy through foreign direct investments (FDI). However, a major concern in most regions in Africa is the differential access to clean energy in rural and urban communities. Energy sector Management[5,17] reports that the total number of households in SSA that have transitioned to using modern energy cooking services is 210 million households, and this comprises 16.6% of urban households and 8.8% of rural households. The difference in the choices and use of different energy sources for cooking has generated mixed results. Various scholars have identified different factors that influence clean energy use for cooking as rapid urbanization, rural–urban population, off-farm work, income, rising cost of charcoal in the urban areas, change in taste, and preference of energy choices, credit access, price, deficit supply, poverty, etc.[2,5,18-21]

Energy is important for sustainable development of any economy, and this calls for policy actions to drive a transition to clean energy use. The costs of inaction for health, gender, and climate/environment resulting from nonclean cooking are highest in SSA compared to other regions of the world. An estimated cost of inaction of US$186.2 billion and 47.5 billion for both gender and climate/environment respectively, and costs implications on health estimated at US$ 96.3 billion[5] raises concern on the urgency for strong policy actions and investment on cooking energy. The health cost is driven by morbidity costs and multiple illnesses from Household Air Pollution (HAP). HAP accounted for 3.2 million premature deaths in 2020.[22] This reiterates the urgency for foreign direct investments (FDI) to accelerate the energy transition in SSA in order to meet the 2030 target.

Most countries in SSA are endowed with adequate natural and mineral resources, however, the majority of its population lacks access to clean fuels and technologies for cooking. The factors that determine access to clean cooking fuels in the region are a matter of concern and action. The related literature documents determinants of access to clean cooking fuels and technologies at the micro or household level, and this includes household income, gender of the household head, fuel prices, household head's educational level, and household size.[13,23–32] Okereke et al.[27] in their study on factors that facilitate transitioning to clean cooking fuel (LPG), found that household size, membership in cooperative societies, gender, and education, significantly influence the transition to clean cooking fuels. At the macro-level involving countries in SSA, most studies focus on access to electricity as a proxy for clean cooking fuels. Such studies remain skewed to demand-side issues relative to the supply side. Generally, the literature establishes factors that influence access to electricity, clean cooking fuels, and technologies to include urbanization,[33,34] income,[14,35–39] financial development,[40–42] electricity price, employment,[43,44] manufacturing activities,[45] and the economic structure of a country.

Foreign direct investment (FDI) has been identified as an important factor that improves the expansion of electricity. Indeed, D'Amelio et al.[46] concluded that FDI facilitated access to electricity in SSA. The extant literature is limited on how FDI as a covariate influences access to clean cooking fuels. Magazzino[40] opined that financial development enhances industrial growth. Further credence is given to this assertion by Chang[47] who underscored that financial development facilitates the use of energy-efficient technologies. There appears to be a mixed effect of FDI on energy consumption. For instance, Rafindadi et al.[48] show that in Gulf Cooperation Council Countries, financial development reduced energy consumption. Inverse relationships were further identified between financial development and energy consumption in India,[49] however, positive effects were found in Tunisia,[50] Pakistan,[51] Malaysia,[42] and China.[52] Chang[47] found mixed accounts of both positive and negative effects, whereas, in Italy, Magazzino[40] identified an insignificant effect.

Many scholars have conducted studies on clean energy. Alola et al.[41] examined the equilibrium relationship between trade openness, real GDP, ecological footprint, fertility rate, nonrenewable energy, and renewable consumption. Usman et al.[42] examined the effects of energy consumption, globalization, and democracy on environmental degradation in South Africa. Usman et al.[42] assessed the role of economic growth, ecological footprint, and democracy in enhancing electricity consumption in Brazil. Kwakwa and Adusah-Poku[11] examined the determinants of clean fuels in South Africa. However, few studies have investigated the link between fuels choices for cooking and economic development.[53-56] Kwakwa et al.[8] appear to be the closest in assessing factors that influence access to clean energy covering 31 SSA where they modeled access to clean cooking fuels and technologies as a function of FDI, income, political regime, employment, and inflation for the period spanning 15 years (2000–2015).

Kwakwa[36] found a positive effect between urbanization on electricity consumption and clean fuel consumption. In the case of Ghana, Kwakwa and Alhassan[57] identified a positive influence of urbanization on energy consumption. Aboagye[58] provided a contrary finding that urbanization does not significantly influence energy intensity in Ghana, but rather a positive relationship existed between energy consumption and urbanization. In China, Li and Lin[34] identified both the negative and positive effects of urbanization on energy consumption based on the economic development stage. Kwakwa[36] reported a positive relationship between urbanization and electricity consumption, but in terms of energy intensity, a negative effect was identified in Tunisia. Khobai and Le Roux[59] identified that urbanization granger-cause electricity consumption in South Africa.

There is no consensus among researchers regarding the factors that influence clean cooking fuels and technologies and their effects. Even more compelling is the paucity of studies on the determinants of clean fuels and technologies using macroeconomic indicators and considering multiple countries in SSA. It is, however, important to guide policy within the sub-region about the direction of the factors. This article seeks to deepen our understanding of the factors that determine clean fuels and technologies for cooking in SSA using macroeconomic indicators. Specifically, this study examines the effect of geography (rural and urban), gross domestic product (GDP) per capita, natural resources depletion, particulate emission damage, and foreign direct investment on access to clean cooking fuels and technologies. Relying on a robust estimation technique (panel autoregressive distributed lag framework—ARDL), this study attempts to deepen the understanding of the factors that affect clean cooking fuels and technologies in SSA coupled with the direction of the relationships of the covariates (rural population, GDP per capita, natural resources depletion, particulate emission damage, and FDI) to illuminate the policy implications for the sub-region. This study therefore assessed the long-run and short-run determinants of access to clean energy in Africa.

The rest of the article is structured as follows: this section presents the introduction, and the next section presents the methodology of the study. Section 3 presents the results and discussion. The final section (Section 4) concludes and offers policy recommendations worthy of consideration by policymakers in SSA.

2 | METHODOLOGY

2.1 | Data source

This paper focused on the African continent where access to clean fuels and technologies is still low. We used data from 38 countries in Africa (see Table 1 for details).

We used available data between 2000 and 2020 from 38 countries in Africa. The choice of the countries and period studied were informed by data availability. We obtained all the data used for this study from the World Bank World Development Indicator Database. We used data spanning a period of 21 years (2000–2020). Access to clean fuels and technologies for cooking was the dependent variable while, rural population, foreign direct investment net inflow, GDP per capita, natural resources depletion, and particulate emission damage were the independent variables. The dependent and independent variables were described and presented in Table 2.

TABLE 2 Description of the variables.

Variables	Source
Rural population (% of total population)	World Development Indicator Database of World Bank
Access to clean fuels and technologies for cooking (% of population)	World Development Indicator Database of World Bank
GDP per capita (current US$)	World Development Indicator Database of World Bank
Adjusted savings: natural resources depletion (% of GNI)	World Development Indicator Database of World Bank
Adjusted savings: particulate emission damage (% of GNI)	World Development Indicator Database of World Bank
Foreign direct investment, net inflows (BoP, current US$)	World Development Indicator Database of World Bank

Note: Link to the data: https://databank.worldbank.org/source/world-development-indicators#.

TABLE 1 List of countries studied.

Algeria	Egypt	Mauritania	Sierra Leone
Angola	Equatorial Guinea	Mauritius	South Africa
Benin	Eswatini	Morocco	Tanzania
Botswana	Ethiopia	Mozambique	Togo
Burkina Faso	Gabon	Namibia	Tunisia
Cameroon	Ghana	Niger	Uganda
Chad	Kenya	Nigeria	Zambia
Congo Republic	Madagascar	Rwanda	Zimbabwe
Congo Democratic Republic	Malawi	Sao Tome and Principe	
Côte d'Ivoire	Mali	Senegal	

TABLE 3 Descriptive statistics.

	N	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
Rural population (% of total population)	798	9.91	85.39	57.82	17.51	−0.33	−0.56
Access to clean fuels and technologies for cooking (% of population)	798	0.10	99.90	28.49	33.69	1.10	−0.23
GDP per capita (current US$)	798	111.93	22942.61	2250.51	2876.60	3.13	13.94
Adjusted savings: natural resources depletion (% of GNI)	798	0.00	100.61	8.77	11.75	2.98	12.82
Adjusted savings: particulate emission damage (% of GNI)	798	0.14	7.14	1.81	1.19	1.28	1.98
Foreign direct investment, net inflows (BoP, current US$)	798	−7397295409.00	11578100000.00	926697070.68	1736323914.57	2.23	10.34

2.2 | Analytical strategy

We used the panel autoregressive distributed lag model to examine the long-run and short-run impacts of gross domestic product per capita, natural resources depletion, particulate matter emission, rural population and foreign direct investment on access to clean cooking fuels and technologies. The implicit model of our panel autoregressive distributed lag framework is stated as follows:

$$Y = f(X1, X2, X3, X4, X5, e) \tag{1}$$

where Y is the Access to clean fuels and technologies for cooking (% of the population). X_1 is the Rural population (% of total population). X_2 is the GDP per capita (current US$). X_3 is the adjusted savings: natural resources depletion (% of GNI). X_4 is the adjusted savings: particulate emission damage (% of GNI). X_5 is the foreign direct investment, net inflows (BoP, current US$). e is the error term.

To reduce inherent heteroscedasticity in the dataset, we transformed the observed values of the variables to their natural logarithms and used the log values for the panel autoregressive distributed lag analysis.

3 | RESULTS AND DISCUSSION

3.1 | Summary statistics

The result, as presented in Table 3, shows the descriptive statistics of the dependent and independent variables. The average rural population in the continent was 57.82% of the total population, and an average of 28.49% of the population in the continent had access to clean fuels and technologies for cooking. The average population in the continent with access to clean fuels and technology is poor, and this may imply their dependence on solid fuels, for example, biomass, which has grave implications on the health, and safety of the household members, especially women and children, and the environment. IEA, IRENA, UNSD, World Bank, WHO[6] reports that globally, in the past decade, there is a 12% increase in the number of people with access to clean fuels and technologies, however, the reverse is the case in sub-Saharan Africa, because the gains in the increase of persons with access to clean fuels and technologies has not kept pace with population growth in the region.

The average GDP per capita was US $2250.51, the average adjusted natural resources depletion (% of GNI) was 8.77, the average adjusted particulate emission damage as a percentage of GNI was 1.81, and the average net foreign direct investment was US $926,697,070.68. GDP per capita may be an estimation of the intensity of energy poverty in this region, as Bonjour et al.[60] in their study found that countries with lower GDP per capita had a higher reliance on solid fuels than countries with higher GDP per capita.

3.2 | The trend of the dependent and independent variables

The trend of the rural population across different countries in Africa is shown in Figure 1. The trend shows a generally declining rural population in all the countries. Mali, Niger and Rwanda are shown to have the highest rural population, and the rural population seems to be relatively unchanged from 2000 to 2020. Rural depopulation over the years has been attributed to many factors, like out-migration, an aging population, increasing mortality rates for some age groups, and lower fertility.[61–64] Provision of quality services for example clean fuels and technologies may positively impact the rural areas, as it may be a policy directive to raise the quality of life of rural people.

The trend of access to clean fuels and technologies (% of the total population) as shown in Figure 2 shows mixed results. Some countries depict an increasing trend characterizing an increase in the number of families with access to clean fuels and technologies (Botswana, South Africa, Eswatini, Gabon, Congo Republic, Cote d'Ivoire, etc.). However, Zambia and Senegal show a declining trend, and this calls for a closer investigation. Using WHO guidelines on access to clean fuels and technologies as households who primarily rely on electricity, biogas, natural gas, liquefied petroleum gas (LPG), solar or alcohol fuels for cooking,[65] the declining trend in some countries, suggests a dependence on dirty fuels, and this negatively impacts the environment and the health of the household members. The GDP per capita

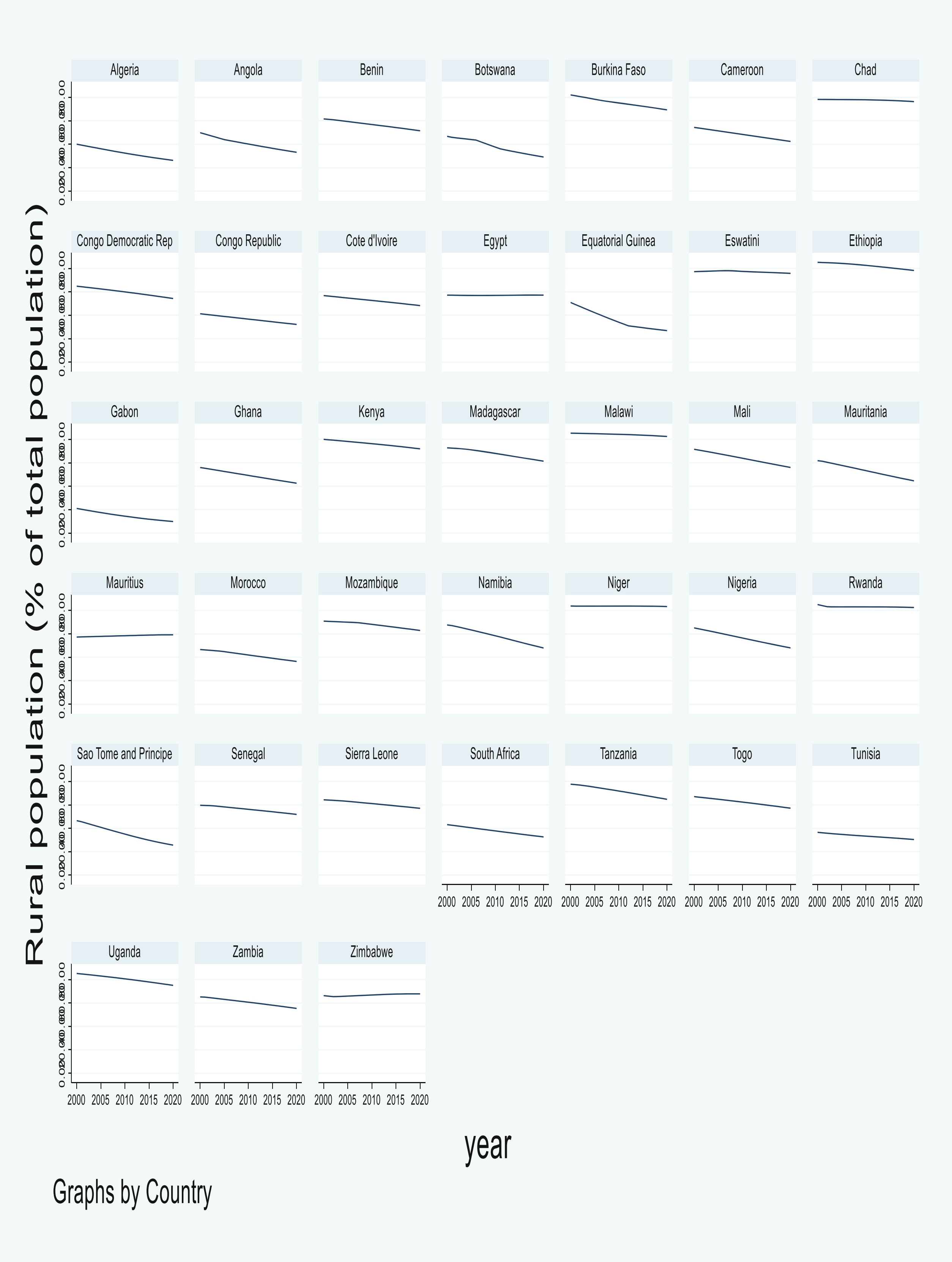

FIGURE 1 Trend of rural population across different countries in Africa.

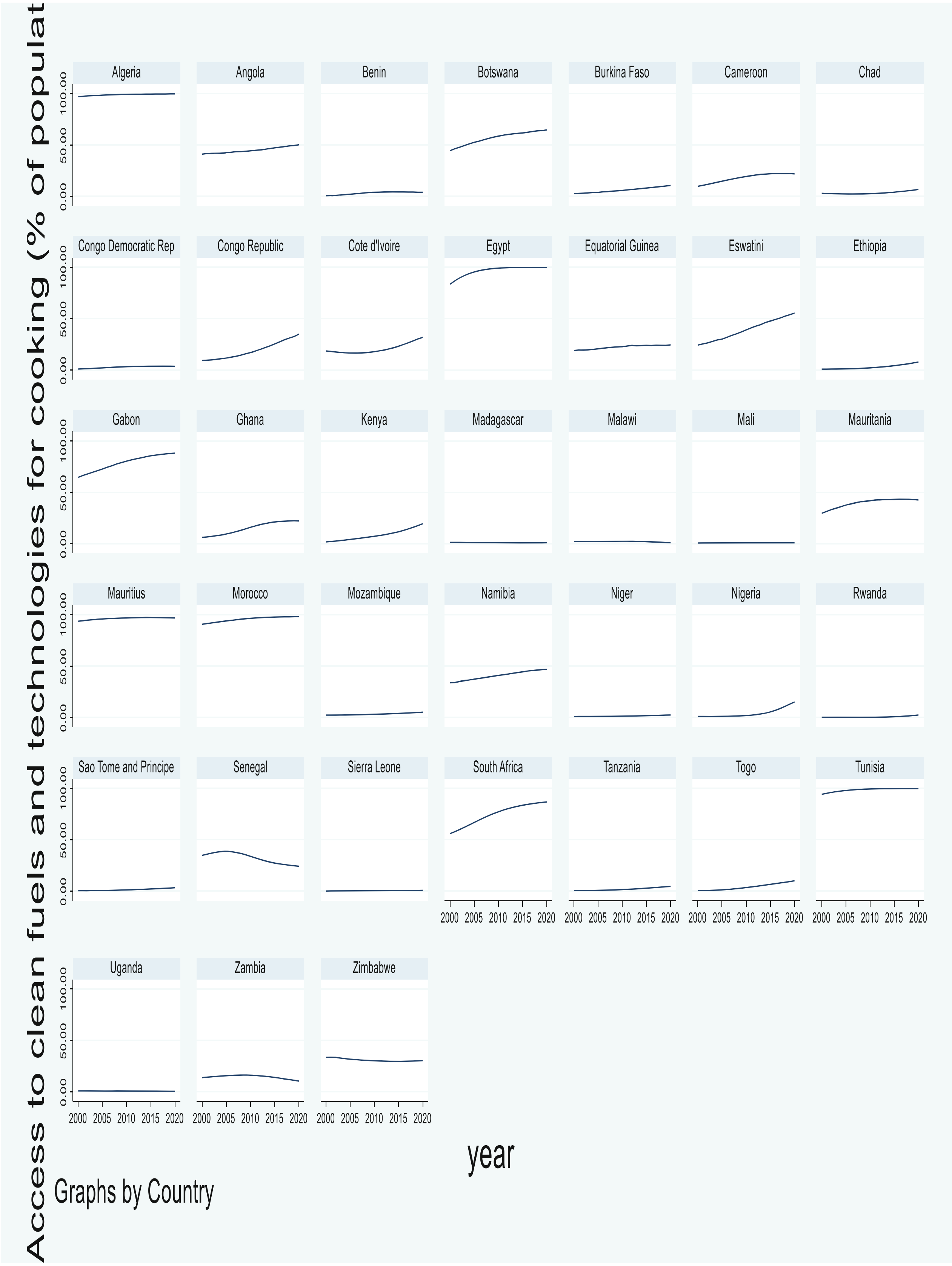

FIGURE 2 Trend of access to clean fuels and technologies for cooking across different countries in Africa.

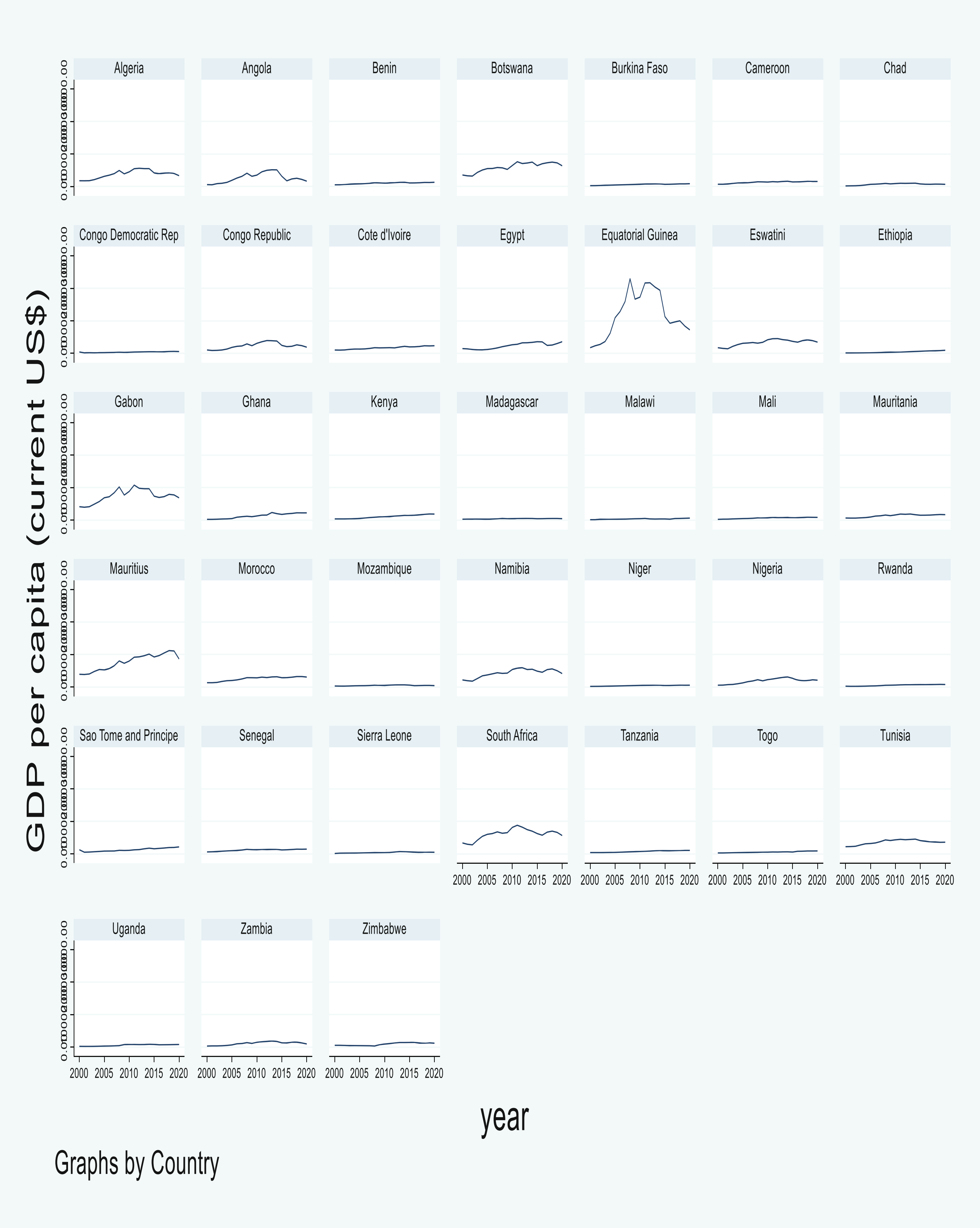

FIGURE 3 Trend of GDP per capita across different countries in Africa.

shows a fluctuating trend across the countries from 2000 to 2020, with Equatorial Guinea showing a sharp decline in GDP per capita within the period under study (Figure 3). Countries such as Mali, Madagascar, Mozambique, Sierra Leone, and Congo Republic show a relatively steady state-equilibrium in GDP per capita in the period 2000–2020.

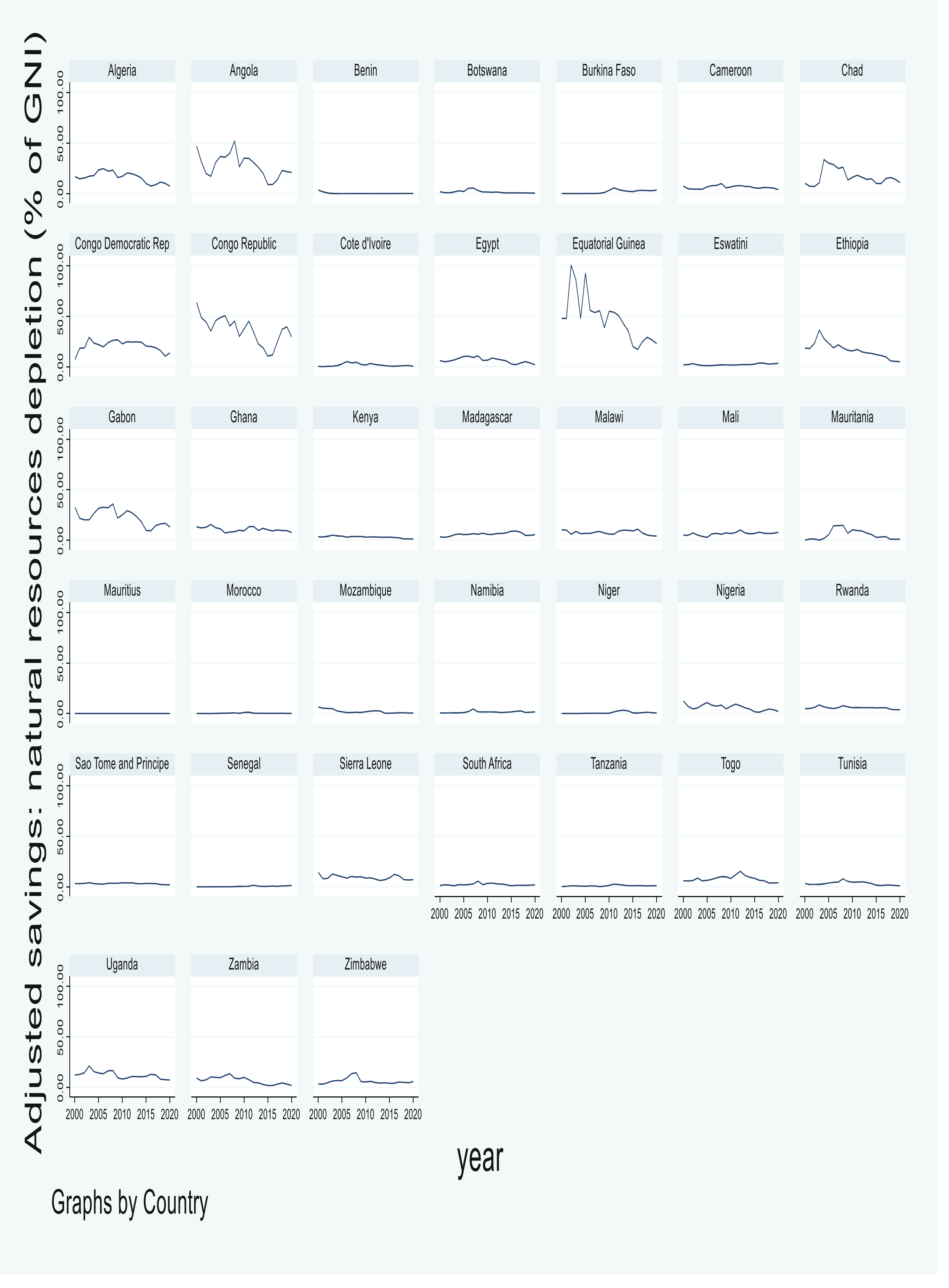

FIGURE 4 Trend of natural resources depletion across different countries in Africa.

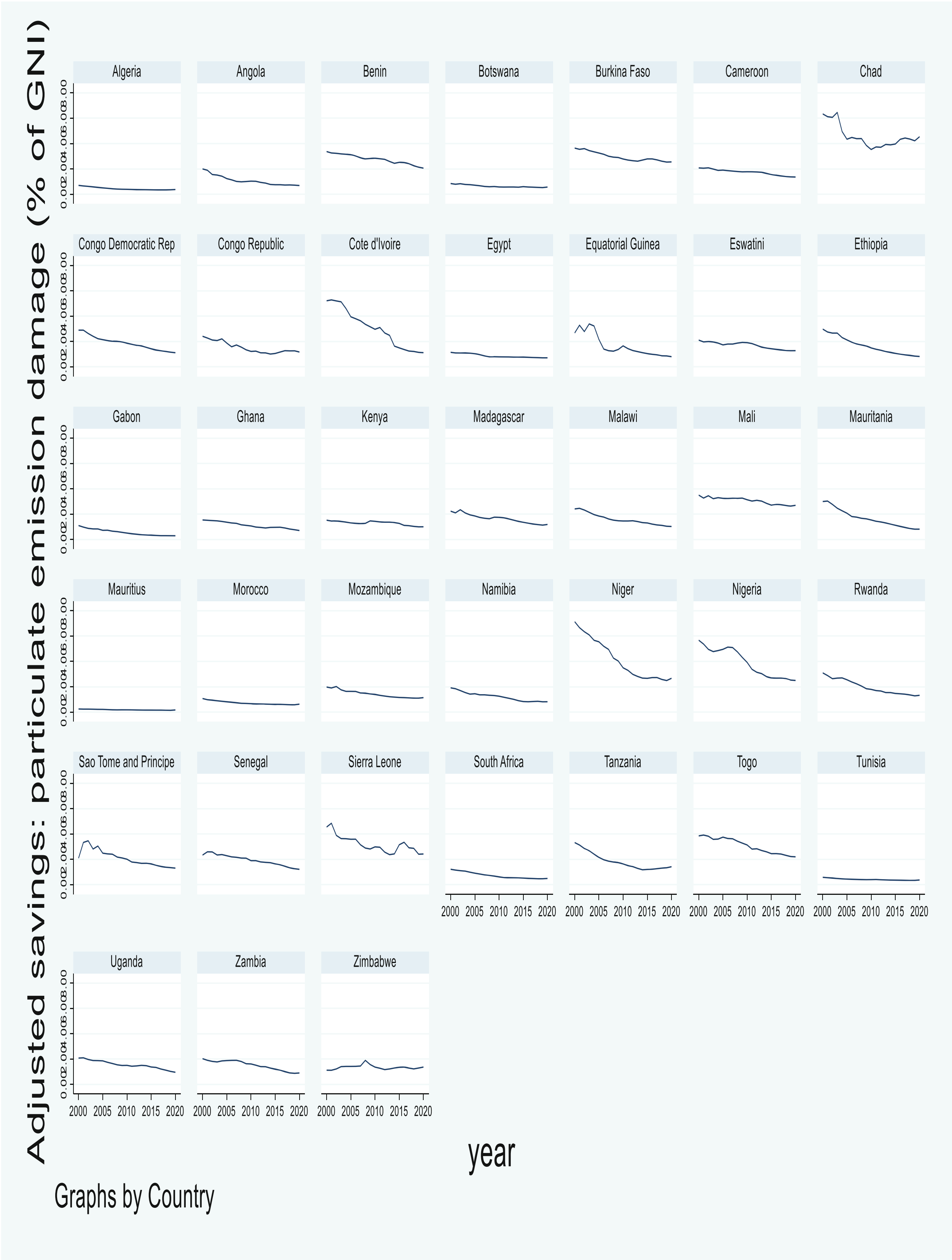

FIGURE 5 Trend of particulate emission damage across different countries in Africa.

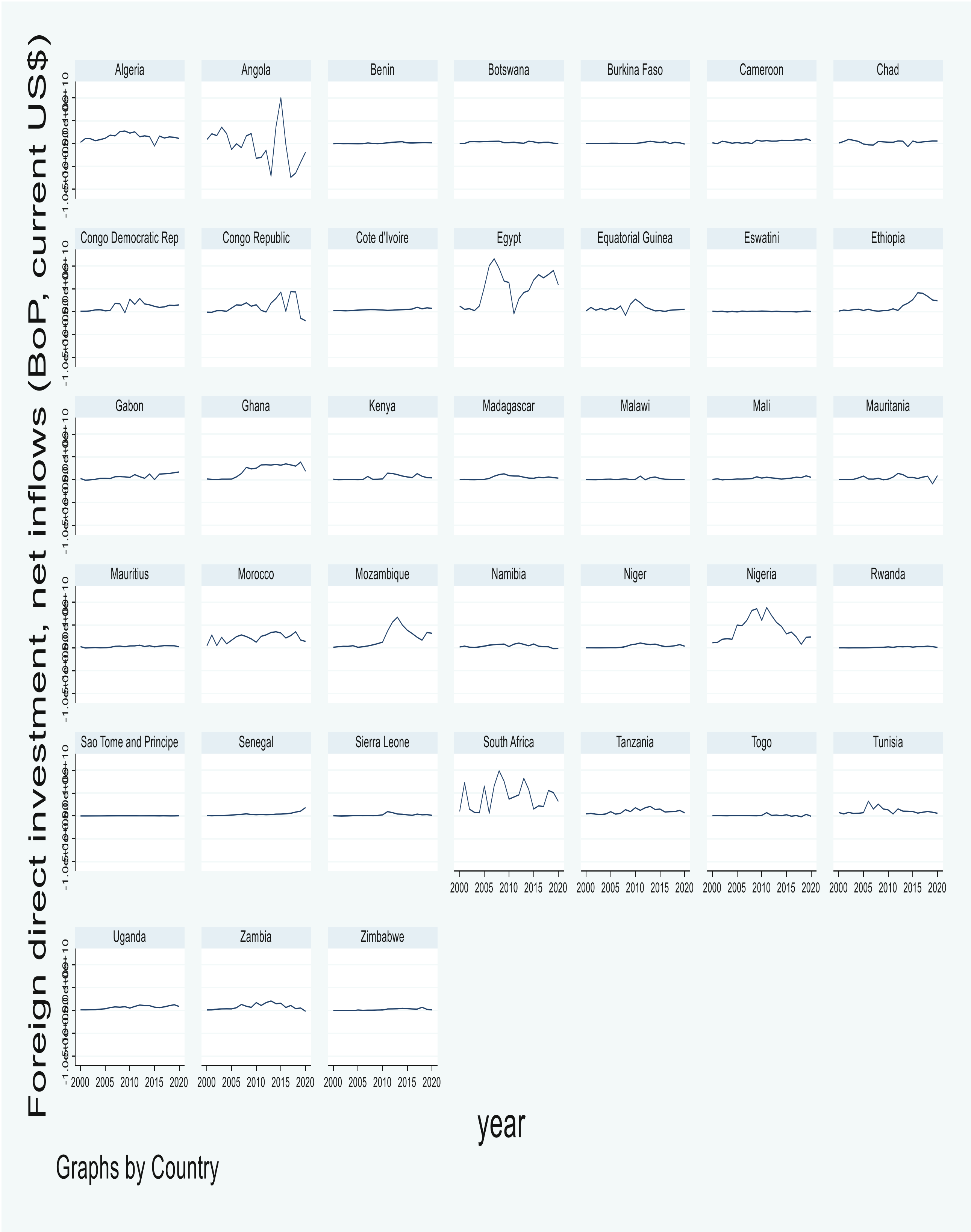

FIGURE 6 Trend of foreign direct investment across different countries in Africa.

The natural resources depletion (% of GNI) shows fluctuating and general declining trends in the countries under study between 2000 and 2020 (Figure 4). Countries like Ethiopia, Equatorial Guinea and Togo show a sharp decline in the adjusted savings: natural resources depletion. Declines in the adjusted savings suggest an over-reliance on the extraction of natural resources, and this does not translate to physical and human capital wealth which is crucial to lifting per capita income. The depletion of forest, energy and mineral resources pose dangers to the environment. Hamilton and Clemens[66] posit that genuine savings in sub-Saharan Africa is negative, and this may be because the rents from natural resources are not adequately invested in human and physical capital development. Hess[67] posits that overuse of renewable and nonrenewable natural resources while improving short-run growth will undermine sustainable development and harm growth in the long run.

The result in Figure 5 shows the trend of adjusted savings: particulate emission damage (% of GNI) across the different countries in Africa from 2000 to 2020. The result shows a generally declining trend in the adjusted savings from particulate emission damage suggesting an increase in particulate matter emission beyond $PM_{2.5}$. This may be attributed to the reliance on dirty fuels. The particulate emission damage captures the foregone labor income due to premature death from the exposure. State of Global Air[68] reveals that 10 countries in Africa, specifically Central Africa Republic, South Sudan, Rwanda, Burundi, Niger, Mali, Madagascar, Tanzania, Uganda, and Guinea-Bissau have the highest proportion of households cooking with solid fuels.

The result in Figure 6 shows the trend in Foreign Direct Investment in the countries from 2000 to 2020. A generally progressive trend in FDI is observed. However, some countries (Nigeria, Angola, Egypt, Congo republic and Mozambique) showed a sharp drop within some years in the period under study. An increase in FDI flows within a country is important for economic growth,[69] and this may increase investments in the provision of clean fuels and technologies.

3.3 | Cross-section dependence test

There is cross-section dependence among the variables in the panel, as shown in Table 4. The null hypothesis of cross-section independence was rejected at a 1% significance level, which justifies that there is cross-section dependence in our panel dataset.

TABLE 4 Cross section dependence test.

Variable	CD-test	*p* Value
lnY	53.70	0.000
lnX1	82.93	0.000
lnX2	103.63	0.000
lnX3	19.16	0.000
lnX4	102.07	0.000
lnX5	21.30	0.000

3.4 | Correlations among the variables

Table 5 shows the correlation coefficients of the variables under consideration. The result shows that access to clean fuels and technologies for cooking exhibited a significantly strong correlation coefficient with the rural population, GDP per capita, adjusted savings from natural resources depletion, and adjusted savings from particulate emission. The correlation coefficient for access to clean fuels and technologies and natural resources depletion, though significant, showed a weak association. The result showed no significant relationship between access to clean fuels and technologies and FDI. The result from the correlation test is just linear associations of the independent variables and the dependent and does not in any way suggest any cause and effect between the selected variables in the long run. The result suggests an association, however, the effects of each variable are further investigated using the panel ARDL model. We subjected this result to further econometric analysis using the panel ARDL.

3.5 | Multicollinearity test for the independent variables

We further subjected the predictor variables to a variance inflation factor (VIF test) to test for multicollinearity (Table 6). The result shows that the VIF for all the variables were <5 signifying the absence of multicollinearity.

3.6 | Stationarity test of the variables

We conducted the unit root test to determine if the dependent and independent variables are nonstationary or stationary. We used the Im–Pesaran–Shin root tests to determine the levels at which the variables were stationary or nonstationary. The result of the unit root test is presented in Table 7. The result shows that natural resource depletion and foreign direct investment were stationary at level under the Im-Pesaran-Shin unit-root tests. Access to clean fuels and technology, rural population, GDP per capita, and particulate emission damage have unit roots under the Im–Pesaran–Shin unit-root test. However,

TABLE 5 Table of correlations among the variables.

Variables	lnY	lnX1	lnX2	lnX3	lnX4	lnX5
lnY	1.0000					
lnX1	−0.5710***	1.0000				
lnX2	0.7717***	−0.6894***	1.0000			
lnX3	−0.1310***	−0.1547***	−0.0886**	1.0000		
lnX4	−0.6908***	0.5386***	−0.6807***	0.1343***	1.0000	
lnX5	0.0446	−0.0124	0.0528	0.0083	−0.1117***	1.0000

Note: z-Values are *p* *** denotes statistical significance at 1%, ** denotes statistical significance at 5%.

TABLE 6 Multicollinearity statistics based on variance inflation factor (VIF).

Variable	Variance Inflation Factor
lnX1	2.162
lnX2	2.640
lnX3	1.134
lnX4	1.964
lnX5	1.018

TABLE 7 Unit root test.

H_0 = All panels contain unit roots; H_0 = series have a unit roots				
Im–Pesaran–Shin unit-root test				
	At level I(0)	At first difference I(1)		
Variable	*t*-statistic	*t*-statistic	Decision: H_0	Result
lnY	2.0993	−6.0650***	Reject	I(1) at 1%
lnX1	3.8720	−13.9842***	Reject	I(1) at 1%
lnX2	3.5914	− 12.0124***	Reject	I(1) at 1%
lnX3	−2.6689***	−10.8794***	Reject	I(0) at 1%
lnX4	3.5104	−6.7710 ***	Reject	I(1) at 1%
lnX5	−4.0393***	−15.6284***	Reject	I(0) at 1%

Note: ** and *** indicate significance at 5% and 1% levels, respectively.

TABLE 8 Cointegration test.

H_0: No cointegration; H_a: All panels are cointegrated		
Test	Statistic	*p* Value
Kao test for cointegration		
Modified Dickey–Fuller *t*	3.9991	0.0000
Dickey–Fuller *t*	4.4794	0.0000
Augmented Dickey–Fuller *t*	3.9184	0.0000
Unadjusted modified Dickey–Fuller *t*	4.7595	0.0000
Unadjusted Dickey–Fuller *t*	5.8346	0.0000
Pedroni test for cointegration		
Modified Phillips–Perron *t*	5.8652	0.0000
Phillips–Perron *t*	−6.8756	0.0000
Augmented Dickey–Fuller *t*	−5.1933	0.0000

all the variables were stationary at the first difference under the Im–Pesaran–Shin unit-root tests, and this suggest the panel ARDL model is appropriate for further analysis to model the impact of the independent variables on the dependent variable.

3.7 | Cointegration test

A long-run relationship between stationary variables can only exist if the variables are cointegrated. Table 8 presents Kao and Pedroni test results between access to clean fuels and technologies for cooking, rural population, GDP per capita, adjusted savings: natural resources depletion, particulate emission damage, and foreign direct investment (FDI) data. This was used to test for an as long-run relationship. The results of the modified Dickey-Fuller *t*, Dickey-Fuller *t*, augmented Dickey-Fuller *t*, unadjusted modified Dickey-Fuller *t*, and unadjusted Dickey-Fuller *t* under the Kao test were all statistically significant at 1% level. Also, the result of the modified Philips-Perron *t*, Phillips-Peron *t*, and augmented Dickey-Fuller *t* under the Pedroni test were all statistically significant at a 1% level. The result implies a long-run relationship between access to clean fuels and technologies for cooking, rural population, GDP per capita, natural resources depletion, particulate emission damage, and foreign direct investment in Africa between 2000 and 2020.

3.8 | Panel ARDL estimates of the determinants of access to clean fuels and technologies for cooking

We used the pooled mean group (PMG) and the dynamic fixed effect (DFE) model to assess the long-run and short-run relationship between the dependent variable (access to clean fuels and technology), and the predictor variables (rural population, GDP per capita, natural resources depletion, particulate emission damage, and foreign direct investment) in the presence of cross-section dependence. The PMG and DFE results are presented in Table 9. The PMG and DFE are second-generation estimation models and we think that PMG and DFE would provide reliable, consistent and efficient results under cross-section dependence. The Hausman test was used to determine the method that best fits our dataset. In addition, we used Hausman tests to determine which model is the most suited. From our result, the PMG is favored and it also had the highest number of significant variables in the short-run and long-run.

The rural population significantly decreased access to clean fuels and technologies in the long run. A 1% increase in the rural population decreased access to clean fuels and technology by 3.465% in the long run. This signifies the effect of a growing population depending on lean resources. The larger the population, the lesser the access to cleaner fuels and technologies, as population growth undermines developmental efforts. ESMAP[49] posits that targeted expenditures for modern energy cooking services using a 10-year scenario should be in sub-Saharan Africa and South Asia with large rural populations.

GDP per capita significantly increased access to clean fuels and technologies in the long run. A 1% increase in GDP per capita increased access to clean fuels and technology by 0.219% in the long run. This implies that populations with higher disposable income have greater access to clean fuels and technologies, in the long run, as this can enable their energy transitions from dirty to clean fuels over time. Kwakwa et al.[8] posit that increasing GDP per capita in Africa has the potential to increase access to clean energy. Growth in GDP is also expected to improve energy intensity of nations, as they transition to the use of more efficient fuels and technologies. However, sub-

TABLE 9 Panel ARDL results from pooled mean group and dynamic fixed effect estimators.

Variables	PMG	DFE
Panel A: Long-run estimates		
lnX1	−3.465	−5.017
	(−5.39)***	(−2.85)***
lnX2	0.219	0.483
	(6.95)***	(1.76)*
lnX3	−0.069	0.024
	(−7.75)***	(0.27)
lnX4	−0.351	1.035
	(−4.78)***	(1.61)
lnX5	0.0002	0.021
	(0.11)	(0.93)
Panel B: Short-run estimates		
ECT	0.030	0.034
	(0.86)	(4.29)***
ΔlnX1	2.876	1.088
	(0.42)	(1.27)
ΔlnX2	0.038	0.010
	(1.03)	(0.52)
ΔlnX3	0.017	−0.005
	(2.24)**	(−1.09)
ΔlnX4	−0.084	−0.018
	(−0.95)	(−0.42)
ΔlnX5	−0.002	0.001
	(−0.66)	(0.84)
Constant	−0.301	−0.553
	(−0.68)	(−2.90)***
Hausman test of poolability (H_0: difference in coefficients not systematic)		
		PMG and DFE
χ^2 (5)		0.17
p Value		0.9994
Decision		The PMG is preferred over the DFE

Note: *z*-Values are presented in parenthesis. *** denotes statistical significance at 1%, ** denotes statistical significance at 5%, and * denotes statistical significance at 10%. ECT is the error correction term/speed of adjustment toward the long run equilibrium.

Saharan Africa, is still far below the improvements in energy intensity globally, and some of this is attributed to the use of solid biomass for cooking.[6]

Adjusted savings: natural resource depletion significantly decreased access to clean fuels and technology in the short and long run. A 1% increase in natural resource depletion decreased access to clean fuels and technology by 0.069% in the long run. Natural resource depletion may connote a high dependence on biomass fuels like wood fuel and charcoal, as well as kerosene or coal. The continued depletion of natural resources has adverse negative effects, as it increases the health burden and impacts the environment. Natural resources should be the basis for wealth creation, as rents from exports can be used to make investments,[70] in this case, investments in clean fuels and technologies.

The result shows that particulate emission damage significantly decreased access to clean fuels and technology in the long run. A 1% increase in adjusted savings: particulate emission damage decreased access to clean fuels and technology by 0.035% in the long run This may imply that particulate matter emissions may result in higher expenditures on health-related issues, like lung and cardiovascular diseases, especially women and children who are directly exposed because of traditional roles in preparing meals.

3.9 | Granger test for panel causality

To determine the causality in our dataset, we used the Dumitrescu and Hurlin[71] Granger test, and the results are presented in Table 10. The existence of long-run relationships among the variables indicates that Granger causality exists in at least one direction for each two variables combination. We find that the lag error terms (ECTt−1) for the rural population, GDP per capita, natural resources depletion, particulate emission damage, and foreign direct investment were significant at the 1% significance level, which confirms the existence of bidirectional causality between rural population, GDP per capita, natural resources depletion, particulate emission damage, and foreign direct investment and access to clean fuels and energy in the long-run.

The result of the causality test as presented in Table 10 shows that access to clean fuels and technologies for cooking Granger causes rural population and rural population Granger-causes access to clean fuels and technologies for cooking (bidirectional causality exists). Access to modern infrastructure (e.g. clean fuels and technology) is a driver of rural out-migration. Johnson and Ifeoma[72] posit that rural population increases lead to out-migration in search of better amenities. Cary[73] posits that access to clean energy and technology is tied to economic development. Rural population Granger causes access to clean fuels and technologies may imply that rural population increases may reduce the percentage of households with access to modern cooking fuels and technologies given the total population. Scott et al.[74] posit that the majority of people without access to modern energy services live in rural areas.

Access to clean fuels and technologies for cooking Granger causes GDP per capita and GDP per capita Granger causes access to clean fuels and technologies for cooking (bidirectional causality exists). Increases in household income increase household consumption of clean fuels and technology, as access may be characterized by an ability to pay for the services. More so, households with higher income may need more efficient energy and modern cooking services that save time and burns more efficiently. Stern[75] reports that energy use and GDP are positively correlated. A study by Garba and Bellingham[76] found a unidirectional causality between solid cooking fuels and GDP per capita, indicating that low GDP per capita may increase households' dependence on dirty fuels.

Our result also shows that access to clean fuels and technologies for cooking Granger causes natural resources depletion and natural

TABLE 10 Dumitrescu and Hurlin (D-H) Granger noncausality test results.

Hypothesis	Z-bar	Z-bar tilde	Remark
lnY → lnX1 lnX1 → lnY	88.2406*** 190.3579***	69.7192*** 150.9374***	Access to clean fuels and technologies for cooking Granger causes rural population and rural population Granger-causes access to clean fuels and technologies for cooking (bidirectional causality exists).
lnY → lnX2 lnX2 → lnY	51.8820*** 33.9200***	40.8017*** 26.5158***	Access to clean fuels and technologies for cooking Granger causes GDP per capita and GDP per capita Granger-causes access to clean fuels and technologies for cooking (bidirectional causality exists).
lnY → lnX3 lnX3 → lnY	21.9994*** 5.7855***	17.0348*** 4.1392***	Access to clean fuels and technologies for cooking Granger causes natural resources depletion and natural resources depletion Granger-causes access to clean fuels and technologies for cooking (bidirectional causality exists).
lnY → lnX4 lnX4 → lnY	52.1013*** 15.5890***	40.9761*** 11.9364***	Access to clean fuels and technologies for cooking Granger causes particulate emission damage and particulate emission damage Granger-causes access to clean fuels and technologies for cooking (bidirectional causality exists).
lnY → lnX5 lnX5 → lnY	13.3213*** 15.2559***	10.1328*** 11.6714***	Access to clean fuels and technologies for cooking Granger causes foreign direct investment and foreign direct investment Granger-causes access to clean fuels and technologies for cooking (bidirectional causality exists).
lnX1 → lnX2 lnX2 → lnX1	103.8712*** 22.6879***	82.1509*** 17.5824***	Rural population does Granger-cause GDP per capita and GDP per capita does Granger-cause rural population (bidirectional causality exists).
lnX1 → lnX3 lnX3 → lnX1	24.0358*** 8.2209***	18.6544*** 6.0762***	Rural population does Granger-cause natural resources depletion and natural resources depletion does Granger-cause rural population (bidirectional causality exists).
lnX1 → lnX4 lnX4 → lnX1	65.6374*** 17.4468***	51.7419*** 13.4139***	Rural population does Granger-cause particulate emission damage and particulate emission damage does Granger-cause rural population (bidirectional causality exists).
lnX1 → lnX5 lnX5 → lnX1	22.6103*** 6.9809***	17.5207*** 5.0900***	Rural population does Granger-cause foreign direct investment and foreign direct investment does Granger-cause rural population (bidirectional causality exists).
lnX2 → lnX3 lnX3 → lnX2	6.1382*** 7.5851***	4.4197*** 5.5705***	GDP per capita Granger causes natural resources depletion and natural resources depletion Granger-causes GDP per capita (bidirectional causality exists).
lnX2 → lnX4 lnX4 → lnX2	9.4608*** 8.6067***	7.0623*** 6.3830***	GDP per capita Granger causes particulate emission damage and particulate emission damage Granger-causes GDP per capita (bidirectional causality exists).
lnX2 → lnX5 lnX5 → lnX2	6.5808 *** 10.0761***	4.7717 *** 7.5517***	GDP per capita Granger causes foreign direct investment and foreign direct investment Granger-causes GDP per capita (bidirectional causality exists).
lnX3 → lnX4 lnX4 → lnX3	9.0299*** 3.2532***	6.7197*** 2.1252**	Natural resources depletion does Granger cause particulate emission damage and particulate emission damage does Granger-cause natural resources depletion (bidirectional causality exists).
lnX3 → lnX5 lnX5 → lnX3	2.5972*** 3.5213***	1.6034 2.3384**	We could not confirm that natural resources depletion does Granger cause foreign direct investment however foreign direct investment does Granger-cause natural resources depletion (bidirectional causality could not be confirmed).
lnX4 → lnX5 lnX5 → lnX4	4.9396*** 5.7366***	3.4664*** 4.1004***	Particulate emission damage does Granger cause foreign direct investment and foreign direct investment does Granger-cause particulate emission damage (bidirectional causality exists).

Note: H_0: one variable does not Granger cause the other variable for at least one panel variable. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels.

resources depletion Granger-causes access to clean fuels and technologies for cooking (bidirectional causality exists). Also, access to clean fuels and technologies for cooking Granger causes particulate emission damage and particulate emission damage Granger causes access to clean fuels and technologies for cooking (bidirectional causality exists). The use of clean fuels and technologies has the potential to reduce particulate emissions, and particulate emissions will be reduced by the use of clean fuels and technologies.[77,78]

Access to clean fuels and technologies for cooking Granger causes foreign direct investment and foreign direct investment Granger causes access to clean fuels and technologies for cooking (bidirectional causality exists). The results imply that foreign direct investment inflow has the potential to increase and develop clean energy technologies that will be beneficial to households. Access to clean fuels and technology may also drive policy actions aimed at improving households' access to clean fuels. This is similar to the findings of Kwakwa[79] who found the existence of unidirectional causality from FDI to access to clean fuels and technologies.

The rural population does Granger cause natural resources depletion and natural resources depletion does Granger cause rural population (bidirectional causality exists). Population explosion particularly in the rural area increases the number of persons relying on natural resources (biomass fuel), especially in low-income earning households. Competition for dwindling natural resources will result in depletion. Sustained pressure on natural resources through unsustainable harvesting of trees and fossil fuels for cooking without corresponding investments has severe consequences in the future. Maja and Ayano[80] posits that rapid population growth is a major threat to sustainable use of natural resources.

The rural population does Granger-cause particulate emission damage and particulate emission damage does Granger-cause rural population (bidirectional causality exists). The unsustainable use of solid fuels and kerosene for cooking especially in poorly ventilated homes raises particulate emission. Particulate emission damage in the rural areas may be a result of the free availability of biomass and limited availability of clean fuels.[81] Natural resources depletion does Granger cause particulate emission damage and particulate emission damage does Granger cause natural resources depletion (bidirectional causality exists). Depletion of natural resources for use in cooking (e.g., tree felling, use of kerosene stoves, etc.) increases particulate matter emission, and this has serious adverse effects on health and the environment. We could not confirm that natural resources depletion does Granger cause foreign direct investment however foreign direct investment does Granger cause natural resources depletion (bidirectional causality could not be confirmed).

4 | CONCLUSION AND POLICY RECOMMENDATIONS

The paper uses panel data from the World Bank World Development Indicator Database for 38 countries in the African continent to study determinants of access to clean fuels and technologies in Africa. Clean fuels and technologies for cooking are important for the health of household members, and environmental health, especially in rural areas. The study concludes that rural population, GDP per capita, particulate matter emission and natural resources depletion determine access to clean fuels and technologies. Rural population growth, natural resources depletion and particulate emission decrease access to clean fuels and technologies in the long run, signifying pressure on the available resources. The use of dirty fuels increases particulate emissions, and the particulate damage from such emissions if not addressed timely will pose serious issues for families dependent on solid fuels. Increasing the GDP per capita will increase the percentage of populations with more access to clean fuels and technologies in the long run in the continent. Policies directed at raising the income levels of households, especially rural populations will drive transitions from dirty fuels to the use of clean fuels ad technologies. Policy actions aimed at improvements in natural resource conservation can be actualized by providing access to clean fuels and technologies in rural areas. This has a multiplier effect as it will increase savings from particulate matter damage, and promote sustainable use of natural resources, which has the potential for economic growth through rents that can be channeled to capital investments. The Government should attract more foreign direct investments through policy regulations that will increase access to clean fuels and technologies.

A UTHOR CONTRIBUTIONS

Robert Ugochukwu Onyeneke, Nneka Maris Chidiebere-Mark, Daniel Adu Ankrah and Louis Uchenna Onyeneke conceptualized the work. Robert Ugochukwu Onyeneke designed the methodology. Robert Ugochukwu Onyeneke and Louis Uchenna Onyeneke managed the literature searches and data entry. Robert Ugochukwu Onyeneke conducted the data analysis. Robert Ugochukwu Onyeneke, Nneka Maris Chidiebere-Mark, and Daniel Adu Ankrah wrote the original draft. Robert Ugochukwu Onyeneke, Nneka Maris Chidiebere-Mark, Daniel Adu Ankrah and Louis Uchenna Onyeneke revised and edited the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known conflict of interest.

D ATA AVAILABILITY STATEMENT

All data used in this study are publicly available.

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