Unbundling the dynamic impact of renewable energy and financial development on real per capita growth in African countries

Amarachi W. Konyeaso1 · Perekunah B. Eregha2,3 · Xuan Vinh Vo4

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Abstract

Industrialization is considered imperative for growth but energy transitions are paramount for inclusive and green growth especially for a region with low financial sector development to spur investment in renewable energy. This study thus unbundles the interrelation among renewable energy production, financial development, and real per capita growth in 32 selected African countries from the period of 1996 to 2018. These countries are categorized on the basis of oil-rich and non-oil-rich as well as income levels. The study employs Pooled Mean Group, Augmented Mean Group, and Dynamic OLS, and key findings are established. The findings reveal a significantly positive renewable energy-economic growth relationship in all the different groups. Financial development is also found to improve economic performance in all categories except in non-oil-rich African countries. These findings empirically support the need for cleaner energy in the production process to spur inclusive and green growth amidst current global concern for climate change and global warning. This study thus recommends the restructuring of the energy pricing system, provision of long-term finance, adoption of risk mitigation instruments, and improved institutional framework for private participation in renewable energy infrastructural development for growth sustainability in Africa.

Keywords Renewable energy · Financial development · Real per capita growth · Pooled Mean Group · Augmented Mean Group · Dynamic OLS

Introduction

The concern for renewables has provided practical alternatives to the toxic fossil fuel approach across the globe. As opposed to fossil fuels, renewable energy (RE) sources are clean, sustainable, and can regenerate (Akam et al. 2022; Konyeaso 2021). Mohsin et al. 2021). Sustainable economic growth (EG) mainly depends on a reliable and functional energy system, prevalence in a particular country or region (Usman et al. 2022). RE is by far the solution to a sustainable energy system. Economic globalization, through financial development (FD), necessitates the need for more energy to smoothen production. Even when it has been established that RE production, as well as consumption, adds to environmental betterment (Li et al. 2022a, b; Murshed et al. 2022; Ahmed et al. 2022; Khan et al. 2022a, b, c), there is still no consensus on the impact of RE on EG (Bulut et al. 2022; Fakher et al. 2022), especially in sub-Saharan Africa (SSA) where the production and consumption of RE are increasingly well embraced. This is the main thrust of the study.

Besides, there has been progress in FD in most SSA countries over the last five decades. However, excluding the middle-income countries in Africa, both financial institutions
and financial markets are not as developed as those obtained in other developing countries of the world (International Monetary Fund (IMF), 2016). The development of Pan-African banks has enhanced greater economic integration in the region, and also filled the void left by the US and European banks. SSA’s financial landscape is dominated by the banking sector which accounts for the biggest share of assets. Although in some SSA countries (like São Tomé and Príncipe, Guinea, Madagascar, and Guinea-Bissau), foreign subsidiaries own the major share of assets. A general look at financial sector development in the region reveals that, over time, financial depth has improved, but there is still a huge gap when compared to the advanced economies mainly due to the low average income level in Africa. For instance, in Fig. 1, domestic credit to the private sector (% of GDP) was 56.8 in 1995, compared to 137.3 and 80.9 in OECD and East Asia and Pacific, respectively. In the year 2000, it increased to 51.5 in SSA. Still for SSA, it was 39.0, 46.7, and 43.0 in 2002, 2003, and 2013, respectively. However, it dwindled to 39.9 and 37.9 in 2019 and 2020, respectively. Figures 2 and 3 (see, Appendix) show the outcomes from other indicators of FD. As per RE production, the region produces more biofuel, also known as agrofuel, which is derived from biomass, and less nuclear, hydropower, solar, and wind energy, as shown in Fig. 4. However, the production of nuclear, hydropower, solar, and wind energy has witnessed a steady growth over

Fig. 1 Domestic credit to private sector (% of GDP) in SSA. Source: WDI (2022). Note: Where EANP, OECD, and SSA stand for East Asia and Pacific, Organisation for Economic Co-operation and Development, and sub-Sahara Africa, respectively

Fig. 2 Monetary sector credit to private sector (% of GDP) in SSA. Source: WDI (2022). Note: Where EANP, OECD, and SSA stand for East Asia and Pacific, Organisation for Economic Co-operation and Development, and sub-Sahara Africa, respectively
the years from 92,171(TJ), 201,879(TJ), and 11,757(TJ) in 1990 to 144,567(TJ), 489,393(TJ), and 303,543(TJ) in 2019, respectively (International Energy Agency 2022).

There is a tripartite relationship between FD, RE, and EG. FD influences RE through different channels. For instance, a developed financial system can satisfy the financial needs of customers, who can also use finance to meet and increase their energy demand. Also, the private sectors can increase their usage of renewables, through access to financial capital, for production purposes, thus enhancing EG. Besides, FD can efficiently lower RE costs through functions like risk mitigation and transparency. Even the inflow of FDI can increase RE production by facilitating the development of knowledge, technologies, and skills (Anton and Nucu 2020). There are, however, two hypotheses that connect FD to EG: the supply-leading and demand-following hypotheses. The former argues that financial markets and institutions promote the supply of various financial services that trigger EG. Meanwhile, the later (demand-following hypothesis) posits that EG enhances the demand for financial services, hence resulting in an expansion in the financial system and growth of the economy (An et al. 2021).

The study attempts to answer the specific research question of whether RE production and FD improve EG in SSA. This study utilized domestic credit to the private sector, a popular measure of FD, to unveil the effect of FD on EG in SSA countries. The outcome of various climate conferences, including COP21, has driven many economies to develop a framework to reduce energy use so as to minimize energy emissions and waste, thereby enhancing sustainable development. EG overwhelmingly depends on energy consumption (Liu et al. 2022; Nathaniel 2021b). As such, it is important for the planning of energy conservation policies to embrace the direct connectivity among the aforementioned variables (Adekoya et al. 2022; Akram et al. 2021). This study will provide valuable knowledge for energy-saving policymaking and the process of growth, and also add to the sustainable development literature. Now, notwithstanding the crucial role of RE, empirical evidence on RE’s impact on growth in Africa is quite thin and murky. There are recent studies on the interaction between RE consumption and EG (Bulut et al. 2022; Fakher et al. 2022; Mohsin et al. 2021), but a dearth of literature exists for studies on the effect of RE production on EG, especially for SSA.

The novelty of this study is in two aspects: (i) it enriches the literature on the relationship between RE production and EG and its causal association. This study is a maiden attempt in estimating the heterogeneous effects of RE production and FD on EG, particularly for SSA economies. This research furthers the global debate on RE production and its influence on EG for SSA economies. In addition, this topic has significant policy implications for energy policies especially by unbundling the SSA into oil and non-oil rich as well as low and middle-income levels on the RE, FD, and EG connection. This is considered imperative for policy direction, especially with the varying levels of income and energy sources in these countries. For instance, several oil-rich nations in Africa face the problem of inadequate capital investment in harnessing renewable energy resources as most of these countries are either into low- or middle-income countries (Konyeaso 2021). (ii) The study also contributes methodologically via the use of advanced first and second-generation dynamic heterogeneous panel data techniques-the Pooled Mean Group, Augmented Mean Group, and Dynamic OLS depending on the post-estimation test for each category. The Augmented Mean Estimator (AMG) is used for data estimation. The decision on this technique (AMG) is that it addresses two core panel data issues, including heterogeneity and cross-sectional dependence (Eregha et al. 2022; Nathaniel 2021a,c; Akram et al. 2021). The PMG allows short-run parameters, intercept and error
variance to vary across groups but derives the long-run parameters from an ARDL model for each country (Pesaran and Smith, 1995).

This research is structured as follows: After this brief introduction, a literature review follows in the “Brief empirical review” section. The methodology is described in the “Model and data” section. The findings are discussed in the “Empirical analysis” section while concluding remarks with some policy directions in the “Conclusion” section.

Brief empirical review

Studies on energy and EG have proliferated after the study of Kraft and Kraft (1978) which focused on the US economy. Similar research was carried out in many economies and regions of the world amidst varying datasets and methodological approaches. The findings of the studies are diversified, with no consensus on the direction of causality between both variables (Eregha et al. 2022; Meo et al. 2021; Ali et al. 2020). As such, research on the energy-growth nexus will continue to grow which is justified (Rahman & Velayutham, 2020). Literature on energy consumption and EG nexus is in four strands which include the growth hypothesis, feedback hypothesis, conservative hypothesis, and the neutrality hypothesis. The growth hypothesis emphasized that energy consumption drives EG. Studies that validated this hypothesis include (Khan et al. 2022a; Zallé 2019; Bekun et al. 2019; Maji et al. 2019; Charfeddine and Kahia, 2019). The category of studies under the feedback hypothesis stressed that a bidirectional causality exists between both variables (see Akram et al. 2021; Kabouli 2019; Bazarcheh Shabestari 2018). Studies under the conservative hypothesis believed that the direction of causality is from EG to energy consumption (Wang et al. 2021; Destek, 2016; Azlina et al. 2014; Ocal & Aslan 2013). The neutrality hypothesis argues no linkage between EG and energy consumption (see Polat, 2021; Pegkas 2020; Mahi et al. 2019).

Magazzino et al. (2021) used the machine learning experiments to explore the association between RE and EG in Brazil from 1990 to 2018. They were able to confirm that RE is a prerequisite for EG in Brazil. Also, Rahman and Velayutham (2020) applied the FMOLS technique to South Asian data spanning 1990 to 2014, to unveil the effect of RE on EG. In line with the study of Asiedu et al. (2021) for 26 EU economies, they reported a positive relationship between RE and EG. Interestingly, while accounting for energy efficiency, population, and trade, Akram et al. (2021) discovered that RE exacts a negative impact on EG. Suffice to say that, RE does not enhance EG in BRICS countries. The authors further justified their findings on the ground that RE production is still at the initial phase in BRICS countries due to limited financial resources.

Also, a number of studies specifically examined the tripartite relationship among energy, financial development, and economic growth. For instance, the ARDL methodology was used by Wang et al. (2021) on the interrelation among renewable energy usage, financial development, and economic performance at the national and regional levels in China from 1997 to 2017. Economic performance was found to intensify renewable energy use while financial development adversely affected energy use. Charfeddine and Kahia (2019) also employed the vector autoregressive model to investigate the impact of renewables and financial development on carbon emissions and economic growth in Middle Eastern and North African countries. Renewable energy utilisation and financial advancement were found to have minimal impact on economic performance. Mahi et al. (2019) on the other hand investigated the relationship among energy use, financial development, and economic growth in five Asian countries from 1980 to 2017. The usage of a structural break revealed that the break has no effect on the association among energy, finance, and growth.

Table 1 summarizes previous studies on energy, FD, and EG nexus.

Model and data

For the impact of renewable energy production and financial development on economic growth, the study follows a framework as espoused by Romar (2012) which assumes a Cobb–Douglas production function of the Solow extension to account for natural resources. Assume a Cobb–Douglas function as:

$$Y_{it} = AK_{it}^{a}L_{it}^{b}R_{it}^{(1-a-b)}$$

where Y = output, K = stock of physical capital, R = natural resources stock (renewable energy), and A = total factor productivity.

Expressing the variables in per worker term and then taking the log, we have:

$$\log \left( \frac{Y_{it}}{L_{it}} \right) = \ln A + a \ln \left( \frac{K_{it}}{L_{it}} \right) + (1 - a) \ln \left( \frac{R_{it}}{L_{it}} \right)$$

where y = output per worker and k = capital stock per worker.

Growth is an accumulation of factors of production and the productivity of these factors and financial development is considered to affect growth through two channels: (i) total factor productivity channel and the investment channel. Thus, assuming financial development is proportional to total factor productivity:

$$A = \alpha F^{\theta}$$

Substituting (3) into (2) in natural log of A:

$$\log \left( \frac{Y_{it}}{L_{it}} \right) = a + \theta \log F_{it} + a \log \left( \frac{K_{it}}{L_{it}} \right) + (1 - a) \log \left( \frac{R_{it}}{L_{it}} \right)$$
| Author(s)                    | Variables                                                                 | Country(s)/region                              | Methodology                  | Findings                                                                                                                                                                                                 |
|-----------------------------|----------------------------------------------------------------------------|-----------------------------------------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Inal et al. (2022)          | EG, RE, carbon emissions,                                                  | Africa oil-producing countries                | AMG estimator; Kónya panel causality | No effect of RE on EG                                                                                                                                                                                     |
| Wang et al. (2022)          | RE, EG, anticorruption regulation, resource dependence, industrialization, labour, fixed capital | 104 countries                                 | Threshold panel; FMOLS       | There is a positive relationship between RE and EG. Anticorruption regulation and resource dependence are important intermediary factors impacting both RE and EG                                                                 |
| Li et al. (2022a, b)        | EG, RE, EF, non-RE, Urbanization                                          | 120 countries                                 | Fixed effect and Threshold model | RE improves EG. Urbanization strengthens the impact of RE on EG                                                                                                                                            |
| Li et al. (2022b)           | Financial market deepening, Financial institution deepening, Financial deepening index, CO₂ emissions | BRICS                                        | Non-linear ARDL              | Financial market deepening and Financial institution deepening increase CO₂ emissions                                                                                                                     |
| Magazzino et al. (2022)     | RE, EG, carbon emissions,                                                  | Scandinavian countries                        | Granger causality test       | RE → EG                                                                                                                                                                                                  |
| Oliveira and Moutinho (2022)| EG, RE, non-RE, globalization, carbon emissions                           | BRICS                                        | GMM                          | RR and non-RE, and globalization drive EG                                                                                                                                                                |
| Gyimah et al. (2022)        | EG, RE, non-RE, FDI, Gross capital formation                              | Ghana                                        | Granger causality test       | RE increases EG. EG ↔ RE RE → FDI                                                                                                                                                                         |
| Fang et al. (2022)          | RE, EG, R&D, green finance, industrialization, urbanization, FDI          | South Asia                                    | 2-Step OLS                   | R&D promotes green growth in developing nations, especially in South Asia                                                                                                                                |
| Chen et al. (2022)          | EG, RE, interest rate, oil price, Wholesale electricity price             | New Zealand, Norway, and two Canadian provinces | Markov-switching vector autoregression | EG → RE                                                                                                                                                                                                  |
| Jeon (2022)                 | EG, RE, non-RE,                                                           | 47 states in the US                           | GMM                          | Re and non-RE increase and decrease EG, respectively                                                                                                                                                      |
| Dasanayaka et al. (2022)    | EG, RE, trade balance, energy import, GFCF                               | Sri Lanka                                     | Structural equation model    | RE increases EG in Sri Lanka                                                                                                                                                                            |
| Zhao et al. (2022)          | RE, energy efficiency, EG                                                | 286 Chinese cities                            | Data envelopment analysis    | RE development depends on environmental regulation to enhance EG                                                                                                                                          |
| Bilgili et al. (2022)       | Access to electricity, agricultural activities, CO₂ damage, REC, GDP     | 36 Asian countries                            | PQR                          | The EKC holds. Access to electricity declines CO₂ damage, while agriculture activities amplify CO₂ damage                                                                                               |
| Khan et al. (2022a)         | clean energy, economic growth, ecological footprint, Natural resources depletion, trilemma energy balance | Denmark, Sweden, Switzerland                 | Generalized least squares    | Trilemma energy balance, natural resources depletion, and clean energy improve economic growth                                                                                                           |
| Zhang et al. (2022)         | ICT, EDU, CO₂ emissions, GLOB, FD                                        | 48 developing countries                       | PQR                          | EDU, GLOB, and FD increase CO₂ emissions                                                                                                                                                                |
| Khan et al. (2022b)         | World energy trilemma, energy use, economic growth, Investment in non-financial assets, ecological footprint | Top ten countries of SDGs index 2021         | Generalized least square     | Investment in non-financial assets and energy use increases economic growth                                                                                                                               |
| Author(s)          | Variables                                              | Country(s)/region               | Methodology       | Findings                                                                 |
|-------------------|--------------------------------------------------------|---------------------------------|-------------------|---------------------------------------------------------------------------|
| Shahzad et al. (2022) | Export product quality, economic complexity, institutional quality, economic growth, URB, trade, REC | OECD countries                  | FMOLS; PQR        | Economic complexity and export quality induce economic growth          |
| Xie et al. (2022)   | Forest resources, mineral volatility, economic growth  | The globe                       | Frequency domain causal approach | Forest resource volatility → economic growth. Mineral resource volatility → economic growth |
| Irfan et al. (2022) | R&D activities, biomass energy, technological complexity, political institution, cultural behaviour | India                           | Modified Delphi method | Technological complexity is the highest ranked barrier                   |
| Tang et al. (2022)  | Natural resources, FD, business regulation, GFCF, CO₂ emissions | ASEAN                           | Cross-Sectionally ARDL; FMOLS | Natural resources reduce FD. GFCF and business regulation increase FD    |
| Mobsin et al. (2021) | RE, non-RE, EG, GHG, Management Policy, POP           | Asian economies                 | Random effect     | EG ↔ RE                                                                  |
| Doytch & Narayan (2021) | RE, non-RE, EG, FDI, government stability, manufacturing and service growth | Middle-, low-, and High-income countries | Panel regression | RE and Non-RE improve EG in all countries                                 |
| Salari et al. (2021) | RE, residential energy consumption, EG, household size, gas tax | USA                             | GMM               | RE drive EG. Confirming the growth hypothesis for the United States       |
| Anser et al. (2021) | EG, solar, wind, geothermal, biomass and hydropower energy | South Asia                      | PVEC; DOLS        | Various types of RE (solar, wind, geothermal, and hydropower) propel EG in South Asian economies |
| Ivanovski et al. (2021) | RE, EG, non-RE, GFCF, labour force                      | OECD and non-OECD              | Dynamic-CCEMG     | RE, non-RE, and GFCF increase EG for the full sample                     |
| Baz et al. (2021)   | RE, EG, fossil fuel, labour, FDI, capital              | Pakistan                        | Non-linear ARDL   | EG ↔ fossil fuel. FDI → EG                                              |
| Zhe et al. (2021)   | FD, RE, EG                                            | Turkey                          | VAR Model         | RE and FD have no significant influence on EG. However, RE significantly influences FD |
| Khan et al. (2021)  | EG, energy trilemma, non-Re, FD, POP                   | Top ten countries in WATI       | FMOLS; GMM        | Non-RE and FD increase EG                                               |
| Shahbaz et al. (2021) | FD, inflation, EG, RE                                 | Developing countries           | FMOLS             | FD and EG improve RE consumption. The influence of inflation was not significant |
| Wang et al. (2021)  | RE, FD, EG                                            | China                           | ARDL              | EG spurs RE. FD does not influence EG                                    |
| Ozturk et al. (2021a) | Economic growth and CO₂ emissions                    | India, Pakistan, and China     | Tapio decoupling index | Pakistan and India experience expensive negative decoupling and weak decoupling, respectively |
| Author(s) | Variables | Country(s)/region | Methodology | Findings |
|-----------|-----------|-------------------|-------------|----------|
| Ozturk et al. (2021b) | Economic growth, pilgrimage tourism, economic growth, oil prices, energy consumption, CO₂ emissions | Saudi Arabia | FMOLS | Oil prices, number of pilgrims, and energy consumption increase CO₂ emissions. CO₂ emissions → Pilgrimage tourism, Pilgrimage tourism → oil prices, Pilgrimage tourism ↔ economic growth |
| Alola and Ozturk (2021) | Risk to investment, GDP, Renewable energy production, CO₂ emissions | The USA | ARDL | EKC is valid. Renewable energy production increases environmental quality. Risk to investment has no meaningful impact on CO₂ emissions |
| Khan & Ozturk (2021) | FD, income, FDI, trade openness, POP, human capital, CO₂ emissions | 88 countries | GMM | EKC is valid. FD reduces the negative impact of FDI, trade, and income on emissions |
| Islam et al. (2021) | FDI, energy consumption, trade, URB, GLOB, institutional quality, economic growth, innovation, CO₂ emissions | Bangladesh | ARDL simulations’ model | Innovation, FDI, and GLOB negatively impact CO₂ emissions. On the other hand, trade, URB, and energy consumption positively impact CO₂ emissions |
| Rehman et al. (2021) | CO₂ emissions from heat and power sectors, public commercial and residential areas, transport, construction, and manufacturing sectors, economic growth | Pakistan | Non-linear ARDL | CO₂ emissions from transport impede economic progress |
| Charfeddine and Kahia (2019) | RE, FD, EG | Middle Eastern and Northern Africa countries | VAR | RE and FD have minimal effect on EG |
| Mahi et al. (2019) | Energy use, FD and EG | Asian countries | Structural Break Analysis | No effect of energy use and FD on EG |

WETI, POP, GMM, FMOLS, OECD, GFCF, AMG, CCEMG, PVECM represent the World Energy Trilemma Index, population, Generalized method of moment, fully-modified OLS, Organisation for Economic Co-operation and Development, Gross fixed capital formation, common correlated mean group, and panel vector error correction model, respectively. URB & GLOB represent urbanization & globalization. Also, ↔ and → stand for bidirectional and unidirectional causality respectively.
Equation (4) shows the tripartite relationship among renewable energy, financial development and real per capita growth. In fact, a well-developed financial sector is considered imperative in helping the populace in meeting their energy demand that will invariably facilitate real per capita growth. Also, the private sector can increase their usage of energy (renewables) through access to financial capital, for production purposes, thus enhancing real per capita growth in the economy.

Institutions captured by regulatory quality (RQ) and voice and accountability (VA) are also controlled in the model. Institutions are considered to spur productivity for growth (Romar 2012) (Table 2). Trade openness, which could also influence technological effectiveness, is included in the model as a control variable.

Regulatory quality denotes the capacity of the government to enact suitable policies for the improvement of the private sector. Voice and accountability refer to the ability of a country’s citizens to express their views of governance in an efficient manner. Regulatory quality is used as a metric of institutional quality because efficient policy formulation promotes the development, and of the private sector and encourages private sector investment. Moreover, voice and accountability are also adopted in this study as an institutional quality metric because it also incorporates military participation in democracy and politics which increases corruption and reduces the confidence of investors and capital inflow (Nadeem et al. 2020).

Thus, the empirical model is as follows:

\[
\log(y) = \beta_0 + \alpha_1 \log(kc) + \alpha_2 \log(re) + \alpha_3 \log(RQ) + \alpha_4 \log(FD) + \mu_i \ldots \tag{3}
\]

where \(i = 1, \ldots, N\) denotes the country, and \(t = 1, \ldots, T\) denotes time.

The study extracted data for 32 selected African countries1 for the period of 1996 to 2018. The countries are grouped into oil-rich and non-oil-rich as well as upper middle-income, lower-middle-income, and low-income countries based on UN classification to allow comparative analysis. The study first tests for cross-sectional dependency (CD), performs both first generation and second generation panel unit root tests, then employs the Dynamic OLS, Pooled Mean Group, and the Augmented Mean Group estimators (Eberhardt and Teal, 2010; Pesaran and Smith, 1995) selected based on the cross-sectional dependence test result and Hausman Test. The Kao (1999) and Pedroni (1999) cointegration tests as well as the Westerlund (2005) cointegration test in the presence of CD are used.

The Dumitrescu and Hurlin (2012) test is also applied to ascertain the direction of causality as presented in Eq. (4):

\[
y_{it} = y_i + \sum_{t=1}^{p} \theta_{i} y_{it-t-n} + \sum_{t=1}^{p} \alpha_i x_{it-t-n} + \mu_{it} \tag{4}
\]

\[
\alpha_i = (\alpha_{i(1)}, \ldots, \alpha_{i(p)}) and \gamma_i are fixed, while \theta_{i} and \gamma_i represent the regression coefficient and the autoregressive parameter, respectively.

Climate change and global warming are among the major global uncertainties the world is facing today and the current call for energy transitions due to rising emissions from production processes. This analysis in this study unbundles and provides empirical support for the need to harness the vast deposits of renewable energy deposits in Africa for sustained growth as biomass current accounts for roughly 80% of energy sources in Africa.

Empirical analysis

In the Appendix, correlation results for each classification are presented as the first step to avoid the problem of multicollinearity and the results confirm the absence of multicollinearity issue. Thus, we proceed with the empirical analysis.

Cross-sectional dependence test

The study adopts the Pesaran CD test and the results are presented in Table 3 for each category.

Table 2 Data and sources

| Variable   | Description                      | Measurement                                      | Data sources                     |
|------------|----------------------------------|-------------------------------------------------|----------------------------------|
| g          | Gross domestic product (GDP) per capita | GDP per capita (constant 2010 US$) | World Development Indicators     |
| kc         | Capital formation per head       | Gross fixed capital formation per head (constant 2010 US$) | United Nations statistics        |
| re         | Renewable energy production per capita | Renewable energy power generation per head (kWh) | International Energy Agency      |
| FD         | Financial development            | Monetary sector credit to private sector (% of GDP) | World Development indicators     |
| TO         | Trade openness                   | Exports of goods and services + imports of goods and services as a % of GDP | World Development Indicators     |
| RQ         | Regulatory quality               | Regulatory Quality: Percentile Rank              | World Governance Indicators      |
| VA         | Voice and Accountability         | Voice and accountability: Percentile Rank        | World Governance Indicators      |
For lower-middle-income countries, the null hypothesis of no cross-sectional dependency is rejected thus; second-generation unit root tests are employed and carried out. For non-oil-rich, oil-rich, upper-middle-income, and low-income countries’ categories, we fail to reject the null hypothesis of no cross-sectional dependency; therefore, first-generation unit root tests is adopted.

Panel data unit root test

This study adopts the first-generation unit root tests (Levin et al. (2002), Breitung (2002) Im et al. (2001), ADF-Fisher and PP-Fisher test) for the category without cross-sectional dependence and the second-generation unit root test (Pesaran (2007)) for those with cross-sectional dependence. Tables 4 and 5 present the panel unit tests.

From the test results, it can be observed that all variables in the oil-rich African countries are stationary after 1st difference while the non-oil-rich African countries have a mix of variables.

Also, series in the upper-middle-income African countries are integrated of order one while variables in both lower middle-income African countries and low-income African countries have a combination I(1) and I(0).

Panel cointegration test

The cointegration tests used are Pedroni and Kao tests and Westerlund test (see, Table 6). From the results, cointegration is established for each of the categories depending on the test applied thus implying a long-run relationship among the series in all the categories.

Estimation results

From the Hausman test results, it can be observed that Pooled Mean Group is the preferred estimation technique as both p-values exceed 0.05. Tables 7 and 8 present the PMG, MG, and Dynamic OLS results depending on each category according to pre-estimation diagnosis.

For the oil-producing African countries, renewable energy per capita is found to spur real Capita growth thus emphasizing the importance of African countries to develop the vast renewable energy deposit. A 1% surge in per capita renewable energy production will cause per capita GDP in oil-rich African countries to increase by 0.062%. This supports the growth hypothesis as confirmed by other studies such as Charfeddine and Kahia (2019), Wang et al. (2022), Li et al. (2022a, b), and Fang et al. (2022). Also, financial development is found to be a growth driver. In fact, a 1% rise in financial development will improve per capita GDP by 0.016%. Similar results were confirmed by Charfeddine and Kahia (2019). Similarly, regulatory quality and voice and accountability as institution variables in the model are found to be critical drivers of economic performance. For upper middle-income African countries, similar results are established. A 1% surge in renewable energy power generation per head will increase per capita GDP by 0.037%. Also, a 1% increase in financial development will improve per capita income by 0.105%. For low-income African countries, per capita renewable energy production and financial development are found to positively influence real per capita GDP growth and similar results are established for regulatory quality and voice and accountability. Magazzino et al. (2022), Li et al. (2022a, b) and Charfeddine and Kahia (2019) studies showed similar findings. For non-oil-rich African countries, renewable energy production per head, capital formation, and voice and accountability contribute positively to growth in the long run but financial development had a negative impact both in the short run and the long run on per capita GDP. Similar results are established by previous studies in similar countries. For instance, Jeon (2022), Zhe et al. (2021), and Mahi et al. (2019) also established renewable energy that does not have a positive effect on growth while Wang et al. (2021) and Mahi et al. (2019) confirmed similar results that financial development does not have an effect on growth.

Dumitrescu and Hurlin causality test results in Table 9 also confirmed the direction of causality for policy direction. The result shows renewable energy to have a unidirectional causality running from renewable energy to real per capita growth and bidirectional causality between financial development and real per capita growth. This corroborates the earlier results by confirming the imperativeness of renewable energy generation in African countries to engender inclusive and green growth. However, the need for a well-developed financial sector to provide investment capital to develop renewable energy is also confirmed to spur real growth. This supports similar results established by Fang et al. (2022), Wang et al. (2022), and Charfeddine and Kahia (2019). The findings of this study have some serious policy intuition considering current global uncertainties. For instance, there is rising global attention to environmental sustainability via reduced emissions in the production process as the sources of energy in the production are considered fundamental. Thus, the current global call for the energy transition. However, Biomass still accounts for more than 80% of Africa’s population’s access to energy despite the region’s vast deposits of unutilized renewables owing to insufficient
investment. This study intuitively unbundles the urgent need for energy transition via a developed financial sector to harness Africa’s abundant renewables.

**Policy implication and suggestion**

Energy transition is imperative for inclusive and green growth, especially in a region with major of the populace depending on the environment for daily survival. The finding of renewable energy generation with the capacity to spur real per capita growth in both oil-rich and non-oil-rich as well as low- and middle-income African countries in this study cannot be overemphasized for urgent policy direction to support green and inclusive growth. Also, the imperativeness of the financial market to provide long-term private capital to develop the vast renewable energy infrastructure for sustained growth was also established in this study. The policy implication is the critical need for a well-develop financial market in Africa. Currently, most of the financing for energy and electricity generation is sourced through public funds in Africa. According to the International Energy Agency (2022), less than 40% of Sub-Saharan African governments do not permit private sector participation in energy generation and less than 20% of Sub-Saharan African nations do not allow private sector involvement in electricity transmission and distribution. However, developing renewable energy infrastructure to meet current demand required private sector participation owing to fiscal constraints across countries in Africa. This is because renewables, apart from reducing the amount of carbon emission, can contribute to the diversification of economies by establishing new industries and expansion of the local value chain. This will also result in more employment opportunities.

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**Table 4** Unit root test: oil-rich and non-oil-rich African countries

| Variables | Levin et al | Breitung t-stat | Im et al | ADF | PP |
|-----------|-------------|-----------------|---------|-----|----|
| **Oil-rich African countries (levels)** |
| Logg      | 1.559       | 2.650           | 3.269   | 9.645| 10.148 |
| Logre     | -0.923      | -1.881**        | -0.923  | 25.18| 43.310* |
| Logkc     | -0.478      | 1.608           | 1.072   | 20.347| 31.700*** |
| LogFD     | -0.002      | 0.919           | 0.300   | 20.467| 22.215 |
| LogTO     | -1.345***   | 0.414           | -0.128  | 22.995| 24.376 |
| LogRQ     | 0.638       | 0.599           | 0.517   | 19.325| 37.405 |
| LogVA     | 0.245       | -0.164          | -1.310  | 30.016| 41.354 |
| **Oil-rich African countries (1st difference)** |
| Logg      | -6.699*     | -2.439*         | -5.146* | 71.772*| 329.527* |
| Logre     | -12.215*    | -10.074*        | -10.215*| 121.872*| 245.701* |
| Logkc     | -3.385*     | -3.546*         | -3.431* | 59.294*| 167.384 |
| LogFD     | -3.854*     | -2.420*         | -3.991* | 56.561*| 106.450* |
| LogTO     | -7.771*     | -6.893*         | -7.432* | 89.274*| 153.627* |
| LogRQ     | -11.069*    | -6.682*         | -10.629*| 128.403*| 239.032* |
| LogVA     | -10.641*    | -3.629*         | -9.097* | 106.719*| 153.713* |
| **Non-oil-rich African countries (levels)** |
| Logg      | 0.526       | 1.078           | 1.558   | 36.819| 44.340 |
| Logre     | -3.546*     | 1.543           | -1.174  | 62.358**| 304.739* |
| Logkc     | 1.194       | 0.957           | 1.449   | 28.760| 49.800 |
| LogFD     | -0.729      | -0.911          | 0.480   | 38.804| 54.711*** |
| LogTO     | 0.560       | 2.306           | 1.725   | 29.313| 38.038 |
| LogRQ     | 0.227       | -0.371          | 1.475   | 27.957| 33.327 |
| LogVA     | 0.023       | 0.818           | 0.824   | 38.615| 44.234 |
| **Non-oil-rich African countries (1st difference)** |
| Logg      | -7.992*     | -1.391***       | -5.878* | 124.521*| 261.714* |
| Logre     | -15.821*    | -5.338*         | -13.651*| 218.779*| 384.979* |
| Logkc     | -13.282*    | -4.929*         | -8.781* | 163.023*| 326.763* |
| LogFD     | -11.297*    | -5.805*         | -8.389* | 157.143*| 507.709* |
| LogTO     | -9.060*     | -8.235*         | -9.553* | 163.495*| 276.803* |
| LogRQ     | -6.312*     | -3.454*         | -5.989* | 113.443*| 250.094* |
| LogVA     | -12.086*    | -8.320*         | -9.792* | 167.091*| 253.428* |

*, ** and, *** indicate significance at 1%, 5%, and 10% respectively.
**Conclusion**

Global warming and climate change are “twin evils” that are current global concerns thus necessitating the call for cleaner energy sources in the production process to engender inclusive and green growth. Africa has energy poverty and their main source of energy source is currently non-renewables despite huge deposits of untapped renewable energy sources to spur inclusive and green growth. This is partly due to low investment in renewable energy owing to financial constraints. This study therefore examines the impact of renewable energy production and financial development on real per capita growth for 32 selected African countries classified under oil-rich, non-oil rich and incomes. Depending on the pre-estimation diagnosis outcome for each category, the Dynamic OLS, Pooled Mean Group, and the Augmented Mean Group estimators are deployed in the analysis and interesting results are established. The study reveals renewable energy production to spur real growth in all the different categories confirming the imperativeness of renewable energy. Also, financial development is found to improve economic performance in all

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**Table 5** Panel unit root test: income classification

| Variable           | Levin et al (levels) | Breitung t-stat | Im et al (levels) | ADF | PP |
|--------------------|----------------------|----------------|------------------|-----|----|
| Logg               | 0.297                | 1.792          | 1.056            | 12.082 | 11.929 |
| Logre              | 1.428***             | 0.723          | 0.672            | 10.184 | 13.719 |
| Logkc              | 2.249                | 2.034          | 2.493            | 2.907 | 3.827 |
| LogFD              | 0.864                | -0.778         | -0.406           | 12.928 | 13.194 |
| LogTO              | 1.209                | -1.246         | 0.536            | 8.075 | 9.170 |
| LogRQ              | 1.070                | 1.316          | 0.731            | 6.516 | 10.921 |
| LogVA              | 0.972                | 0.111          | -0.750           | 14.108 | 14.651 |

| Variable           | Levin et al (1st difference) | Breitung t-stat | Im et al (1st difference) | ADF | PP |
|--------------------|-------------------------------|----------------|--------------------------|-----|----|
| Logg               | 8.548*                        | -3.271*        | -6.652*                  | 61.582* | 325.306* |
| Logre              | 11.103*                       | -3.832*        | -9.205*                  | 81.605* | 267.294* |
| Logkc              | 2.971*                        | -2.377*        | -2.358*                  | 27.872* | 50.906* |
| LogFD              | 7.598*                        | -3.415*        | -6.372*                  | 58.210* | 79.728* |
| LogTO              | 2.903*                        | -5.530*        | -3.630*                  | 34.845* | 64.740* |
| LogRQ              | 3.719*                        | -2.561*        | -3.700*                  | 36.811* | 59.445* |
| LogVA              | 7.600*                        | -2.546*        | -5.742*                  | 51.770* | 56.900* |

| Variable           | Levin et al (levels) | Breitung t-stat | Im et al (levels) | ADF | PP |
|--------------------|----------------------|----------------|------------------|-----|----|
| Logg               | 1.192                | -1.912         | 0.910            | 20.90 | 23.002 |
| Logre              | 2.708*               | -4.807*        | -4.507*          | 16.957 | 37.392* |
| Logkc              | 1.640                | -4.330*        | -4.365*          | 13.644 | 20.706 |
| LogFD              | 2.101                | -4.323*        | -4.577*          | 12.393 | 15.949 |
| LogTO              | 1.637                | -4.323*        | -4.577*          | 12.393 | 15.949 |
| LogRQ              | 1.967                | -4.323*        | -4.577*          | 12.393 | 15.949 |
| LogVA              | 2.804*               | -4.457*        | -4.577*          | 12.393 | 15.949 |

| Variable           | Levin et al (1st difference) | Breitung t-stat | Im et al (1st difference) | ADF | PP |
|--------------------|-------------------------------|----------------|--------------------------|-----|----|
| Logg               | 11.426*                       | -7.010*        | -9.523*                  | 110.646* | 114.192* |
| Logre              | 9.373*                        | -3.498*        | -7.818*                  | 93.008* | 175.089* |
| Logkc              | 10.021*                       | -3.403*        | -7.380*                  | 95.159* | 228.892* |
| LogFD              | 10.592*                       | -4.955*        | -7.830*                  | 103.597* | 402.732* |
| LogTO              | 4.886*                        | -4.599*        | -6.692*                  | 84.946* | 157.046* |
| LogRQ              | 4.687*                        | -2.754*        | -4.937*                  | 65.885* | 139.371* |
| LogVA              | 10.148*                       | -5.693*        | -7.777*                  | 94.387* | 158.057* |

Where *, **, and *** indicate significance at 1%, 5% and 10% respectively
different categories except for non-oil-rich African countries where it is established to be a growth drag. The findings of these studies therefore unbundle the urgent policy need for energy transition especially in developing framework for financial market development to attract private capital for renewable energy infrastructure development since the current 80% biomass source of energy is not environmentally sustainable for inclusive growth.

The study recommends the need to allow suitable energy pricing to attract private investment in renewable energy infrastructure in Africa. It is important to strike a balance between providing energy at an affordable rate and making sure the prices are not too low so that private investors will be encouraged. Efforts should also be geared towards mitigating risks involved in renewable energy investment and developing the right institutional framework for private sector participation in renewable energy infrastructural development for growth sustainability in Africa.

This study has contributed to the literature on the renewable energy-growth relationship by accounting for financial development which previous studies paid less attention to.

| Table 6  Cointegration test | Estimates | Statistic | p values |
|--------------------|-----------|-----------|----------|
| Oil-rich African countries (Pedroni and Kao tests) | Panel v-statistic | $-1.603$ | $0.946$ |
| | Panel rho-statistic | $2.902$ | $0.998$ |
| | Panel PP-statistic | $-2.237^{**}$ | $0.013^{**}$ |
| | Panel ADF-statistic | $-2.025^{**}$ | $0.021^{**}$ |
| | Group rho-statistic | $4.384$ | $1$ |
| | Group PP-statistic | $-0.874$ | $0.191$ |
| | Group ADF-statistic | $1.102$ | $0.865$ |
| | Kao ADF | $-3.634^{*}$ | $0^{*}$ |
| Non-oil rich African countries (Pedroni and Kao tests) | Panel v-statistic | $-1.028$ | $0.848$ |
| | Panel rho-statistic | $3.608$ | $1$ |
| | Panel PP-statistic | $-1.340^{***}$ | $0.090^{***}$ |
| | Panel ADF-statistic | $-1.709^{**}$ | $0.043^{**}$ |
| | Group rho-statistic | $4.913$ | $1$ |
| | Group PP-statistic | $-7.664^{*}$ | $0^{*}$ |
| | Group ADF-statistic | $-2.804^{*}$ | $0.003^{*}$ |
| | Kao ADF | $-2.584^{*}$ | $0.005^{*}$ |
| Upper-middle-income African countries (Pedroni and Kao tests) | Panel v-statistic | $-1.071$ | $0.858$ |
| | Panel rho-statistic | $2.105$ | $0.982$ |
| | Panel PP-statistic | $-2.937^{*}$ | $0.002^{*}$ |
| | Panel ADF-statistic | $-2.476^{*}$ | $0.007^{*}$ |
| | Group rho-statistic | $2.814$ | $0.998$ |
| | Group PP-statistic | $-8.033^{*}$ | $0^{*}$ |
| | Group ADF-statistic | $-1.550^{***}$ | $0.061^{***}$ |
| | Kao ADF | $-3.857^{*}$ | $0^{*}$ |
| Lower-middle-income African countries (Westerlund test) | Statistic | $2.3489^{*}$ | $0.009^{*}$ |
| | P-value | $0.009^{*}$ | $0.009^{*}$ |
| Low-income African countries (Pedroni and Kao tests) | Panel v-statistic | $-0.852$ | $0.803$ |
| | Panel rho-statistic | $2.645$ | $0.996$ |
| | Panel PP-statistic | $-0.645$ | $0.259$ |
| | Panel ADF-statistic | $-1.407^{***}$ | $0.080^{***}$ |
| | Group rho-statistic | $3.91$ | $1$ |
| | Group PP-statistic | $-2.690^{*}$ | $0.003^{*}$ |
| | Group ADF-statistic | $-2.117^{**}$ | $0.017^{**}$ |
| | Kao ADF | $-1.805^{**}$ | $0.036^{**}$ |

Where *, **, and *** represent significance at 1%, 5%, and 10% respectively.
The study thus provides avenues to expand the frontier of knowledge in this area. First, this study is limited to 32 countries in Africa, owing to data availability constraints. The results may not be generalizable as caution is required in taking conclusive policy direction for all African countries. Thus, future studies may need to increase the sample size and account for other measures of financial development. Second, the current global challenges such as the Russia-Ukraine war and the COVID-19 pandemic have affected the growth trajectories and financial markets of most African countries.

### Table 7: Estimation results: income classification

| Variable | Coefficient | Standard error | t-Statistic | P-values |
|----------|-------------|----------------|-------------|----------|
| Upper middle-income countries: dependent variable: log of per capita GDP (Dynamic OLS) |
| Logre    | 0.037       | 0.018          | 2.039       | 0.045**  |
| Logkc    | 0.360       | 0.034          | 10.502      | 0*       |
| LogFD    | 0.105       | 0.053          | 1.976       | 0.051*** |
| LogRQ    | 0.146       | 0.066          | 2.188       | 0.031**  |
| LogTO    | 0.051       | 0.051          | 0.605       | 0.547    |
| LogVA    | -0.060      | 0.077          | -0.782      | 0.436    |
| R-squared| 0.837       |                |             |          |
| Lower middle-income countries: dependent variable: Logg (augmented mean group; long run results only) |
| Logre    | 0.034       | 0.016          | 2.18        | 0.029**  |
| Logkc    | 0.099       | 0.032          | 3.09        | 0.002*   |
| LogFD    | 0.029       | 0.021          | 1.37        | 0.170    |
| LogTO    | -0.032      | 0.031          | -1.04       | 0.298    |
| LogRQ    | -0.025      | 0.024          | -1.05       | 0.295    |
| LogVA    | -0.040      | 0.025          | -1.60       | 0.109    |
| Constant | 6.634       | 0.229          | 29.01       | 0*       |
| RMSE     | 0.026       |                |             |          |
| Low-income African countries: dependent variable: log of real per capita GDP |
| Variables | PMG | MG |
| Long run |
| Logre    | 0.033*     | (2.85)        |
| Logkc    | 0.291*     | (22.50)       |
| LogFD    | 0.012      | (0.32)        |
| LogTO    | -0.061     | (-1.41)       |
| LogRQ    | 0.345*     | (10.95)       |
| LogVA    | -0.006     | (-0.14)       |
| Short run |
| EC       | -0.184**   | (-2.24)       |
| D.Logre  | 0.0003     | (0.02)        |
| D.Logkc  | 0.019      | (0.58)        |
| D.LogFD  | 0.001      | (0.04)        |
| D.logTO  | -0.009     | (-0.25)       |
| D.LogRQ  | 0.034      | (0.97)        |
| D.LogVA  | 0.040***   | (1.85)        |
| _cons    | 0.755**    | (2.31)        |
| Hausman test |
| MG vs PMG | 8.3 [0.22] | - |
countries, thus the extension of the current data and analysis to account for these events may provide interesting policy implications. Therefore, future research should find a way to incorporate these issues empirically.

### Appendix

Table 8

| Variable  | Coefficient | Standard error | t-Statistic | P-values |
|-----------|-------------|----------------|-------------|----------|
| Logre     | 0.062       | 0.032          | 1.979       | 0.050**  |
| Logkc     | 0.131       | 0.023          | 5.759       | 0.553    |
| LogFD     | 0.016       | 0.027          | 0.595       | 0.993*** |
| LogRQ     | 0.080       | 0.033          | 2.379       | 0.482    |
| LogTO     | -0.117      | 0.069          | -1.690      | 0.093*** |
| LogVA     | 0.029       | 0.042          | 0.706       | 0.490    |

R-Squared: 0.957
Adjusted R-Squared: 0.936

Table 9

| Ho:          | W-Stat  | Zbar-Stat | Prob |
|--------------|---------|-----------|------|
| RE → G       | 6.08*** | 3.87***   | 0.000|
| G → RE       | 1.12    | 0.96      | 0.321|
| FD → G       | 5.22*** | 4.53***   | 0.000|
| G → FD       | 5.02*** | 4.211***  | 0.000|

*** indicates 1% levels of significance

Table 10

Estimation results: oil-rich and non-oil-rich African countries

| Variable | Coefficient | Standard error | t-Statistic | P-values |
|----------|-------------|----------------|-------------|----------|
| Logre    | 0.062       | 0.032          | 1.979       | 0.050**  |
| Logkc    | 0.131       | 0.023          | 5.759       | 0.553    |
| LogFD    | 0.016       | 0.027          | 0.595       | 0.993*** |
| LogRQ    | 0.080       | 0.033          | 2.379       | 0.482    |
| LogTO    | -0.117      | 0.069          | -1.690      | 0.093*** |
| LogVA    | 0.029       | 0.042          | 0.706       | 0.490    |

R-Squared: 0.957
Adjusted R-Squared: 0.936

Non-oil rich African countries. Dependent variable: log of real per capita GDP

| Variables | PMG   | MG    |
|-----------|-------|-------|
| Logre     | 0.049** |       |
| (2.12)    | 0.277 |       |
| Logkc     | 0.456*  |       |
| (15.94)   | 0.207 |       |
| LogFD     | -0.004  | 0.353 |
| (-0.33)   |       | (1.15) |
| LogTO     | -0.013  | 0.002 |
| (-0.21)   |       |       |
| LogRQ     | -0.438* | 0.245 |
| (-4.82)   |       | (0.91) |
| LogVA     | 0.512*  | -0.900|
| (6.19)    |       | (-0.70) |

R-Squared: 0.912
Adjusted R-Squared: 0.891

Dumitrescu and Hurin causality test result for 32 African countries

| Ho:          | W-Stat  | Zbar-Stat | Prob |
|--------------|---------|-----------|------|
| RE → G       | 6.08*** | 3.87***   | 0.000|
| G → RE       | 1.12    | 0.96      | 0.321|
| FD → G       | 5.22*** | 4.53***   | 0.000|
| G → FD       | 5.02*** | 4.211***  | 0.000|

*** indicates 1% levels of significance

countries, thus the extension of the current data and analysis to account for these events may provide interesting policy implications. Therefore, future research should find a way to incorporate these issues empirically.
Table 10  Correlation matrix

|               | Logg | Logre | Logkc | LogFD | LogTO | LogRQ | LogVA |
|---------------|------|-------|-------|-------|-------|-------|-------|
| **Oil-rich African countries** |      |       |       |       |       |       |       |
| Logg          | 1    | 0.27  | 0.74  | 0.03  | 0.50  | 0.26  | −0.34 |
| Logre         | 0.27 | 1     | −0.46 | 0.04  | −0.07 | 0.55  | 0.39  |
| Logkc         | 0.74 | −0.46 | 1     | 0.15  | 0.37  | −0.33 | −0.28 |
| LogFD         | 0.03 | 0.04  | 0.15  | 1     | −0.21 | 0.23  | 0.32  |
| LogTO         | 0.50 | −0.07 | 0.37  | −0.21 | 1     | −0.09 | 0.04  |
| LogRQ         | 0.26 | 0.55  | −0.33 | 0.23  | −0.09 | 1     | 0.68  |
| LogVA         | −0.34| 0.39  | −0.28 | 0.32  | 0.04  | 0.68  | 1     |
| **Non-oil-rich African countries** |      |       |       |       |       |       |       |
| Logg          | 1    | 0.13  | 0.58  | 0.63  | 0.55  | 0.64  | 0.71  |
| Logre         | 0.13 | 1     | −0.17 | 0.31  | 0.31  | 0.20  | 0.09  |
| Logkc         | 0.58 | −0.17 | 1     | 0.53  | 0.33  | 0.41  | 0.42  |
| LogFD         | 0.63 | 0.31  | 0.53  | 1     | 0.47  | 0.51  | 0.36  |
| LogTO         | 0.55 | 0.31  | 0.33  | 0.47  | 1     | 0.47  | 0.34  |
| LogRQ         | 0.64 | 0.20  | 0.41  | 0.51  | 0.47  | 1     | 0.65  |
| LogVA         | 0.71 | 0.09  | 0.42  | 0.54  | 0.65  | 0.65  | 1     |
| **Upper-middle-income African countries** |      |       |       |       |       |       |       |
| Logg          | 1    | 0.01  | 0.53  | 0.54  | 0.08  | 0.16  | −0.41 |
| Logre         | 0.01 | 1     | −0.51 | 0.20  | 0.01  | 0.40  | 0.39  |
| Logkc         | 0.53 | −0.51 | 1     | −0.51 | 0.26  | −0.70 | −0.74 |
| LogFD         | 0.54 | 0.20  | −0.51 | 1     | −0.38 | 0.32  | 0.57  |
| LogTO         | 0.08 | 0.01  | 0.26  | −0.38 | 1     | −0.01 | −0.01 |
| LogRQ         | 0.16 | 0.40  | −0.70 | 0.32  | −0.01 | 1     | 0.70  |
| LogVA         | −0.41| 0.39  | −0.74 | 0.57  | 0.01  | 0.70  | 1     |
| **Lower-middle-income African countries** |      |       |       |       |       |       |       |
| Logg          | 1    | 0.04  | 0.36  | 0.003 | −0.04 | −0.44 | −0.62 |
| Logre         | 0.04 | 1     | −0.31 | 0.14  | 0.26  | 0.02  | −0.29 |
| Logkc         | 0.36 | −0.31 | 1     | 0.13  | −0.02 | −0.17 | −0.19 |
| LogFD         | 0.003| 0.14  | 0.13  | 1     | 0.45  | 0.24  | 0.29  |
| LogTO         | −0.04| 0.26  | −0.02 | 0.45  | 1     | −0.09 | 0.20  |
| LogRQ         | −0.44| 0.02  | −0.17 | 0.24  | −0.09 | 1     | 0.43  |
| LogVA         | −0.62| −0.29 | −0.19 | 0.29  | 0.20  | 0.43  | 1     |
| **Low-income African countries** |      |       |       |       |       |       |       |
| Logg          | 1    | 0.07  | 0.82  | 0.08  | 0.52  | 0.11  | −0.25 |
| Logre         | 0.07 | 1     | 0.22  | 0.23  | 0.20  | 0.19  | 0.16  |
| Logkc         | 0.82 | 0.22  | 1     | 0.22  | 0.46  | 0.25  | −0.08 |
| LogFD         | 0.08 | 0.23  | 0.22  | 1     | 0.08  | 0.24  | 0.10  |
| LogTO         | 0.52 | 0.20  | 0.46  | 0.08  | 1     | 0.02  | −0.05 |
| LogRQ         | 0.11 | 0.19  | 0.25  | 0.24  | 0.02  | 1     | 0.66  |
| LogVA         | −0.25| 0.16  | −0.08 | 0.10  | −0.05 | 0.66  | 1     |
Author contribution All authors read and approved the final version. The first version was prepared by Konyeason Amarachi under the guidance of Perekunah Eregha as the conception was jointly conceived. Perekunah Eregha provided the literature and the estimation codes. Perekunah Eregha then reworked and improved the first version and it was proofread and significantly finalised by Xuan Vinh Vo. All authors read and approved the final manuscript.

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