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ORIGINAL PAPER

Harmonizing renewable energy and economic growth in Sub-Saharan Africa: the transformative potential of ICT

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Abstract

Despite the positive impact that renewable energy can offer its development is not necessarily and widely implemented by countries. It is against this backdrop this study investigates whether renewable energy contribute to economic growth in sub-Saharan Africa (SSA) between the periods 2005–2022. The study accounted for the role of information communication technology and globalization in stimulating economic growth. For empirical analysis, this study adopted Pooled Mean Group (PMG) Autoregressive Distributed Lag Model approach and other batteries of techniques for robustness testing. It was observed that both renewable energy and information communication technology (ICT) indicate a negative and significant impact on economic growth in the long run. The study further established a positive and significant impact of globalization and economic growth in the long run. This indicates the vital role of ICT and globalization in accelerating economic growth. In terms of policy suggestions, this study believes that infrastructural development, incentives among others could make renewable energy more affordable and attractive for private sector participation. There is also the need to provide research funding to develop home-produced technology to improve energy supply in the region, particularly in rural areas.

Keywords Renewable energy · Economic growth · SSA · PMG · Panel data

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1 Introduction

It is widely known that, although fossil fuels are beneficial for economic activities, they are harmful to sustainability in the long run—either in the form of environmental sustainability (pollution) or human sustainability (negative health effects). Given that understanding, awareness for promoting renewable energy has been increasing, as it is believed that renewable energy can offer a more friendly impact on humans and the environment in the long run. However, despite the positive impact that renewable energy can offer, its development is not widely implemented by countries. One of the challenges of using renewable energy is the fact that fossil fuels are cheaper and more efficient to support production, consumption, and distribution activities. With greater economic activities, fossil fuels are expected to accelerate economic growth at a faster rate. However, these short-term benefits are reaped at the cost of the future environment and human unsustainability.

Sub-Saharan Africa (SSA) is a region grappling with severe environmental challenges during its developmental phase. According to a study conducted by Bauer et al. (2019) at the National Aeronautics and Space Administration (NASA), SSA experiences extreme air pollution that surpasses the clean air standards set by the World Health Organization (WHO). Air quality-related deaths now stand as the leading cause of mortality in Africa (Bauer et al. 2019), with approximately 780,000 premature deaths occurring annually in the region. Moreover, a report from UNICEF (2019) reveals a concerning trend, showing that air pollution deaths across Africa have surged by 60% between 1990 and 2017. These alarming environmental issues in Africa underscore the urgent need for governments to reform energy consumption, shifting from fossil fuels to more sustainable, renewable energy sources.

Unfortunately, the development of renewable energy consumption in SSA is heading in the wrong direction. The World Bank estimates that the share of renewable energy consumption, as a percentage of total energy consumption in the region, has significantly declined since 1994. Specifically, the share of renewable energy consumption in SSA dropped from 73.85% in 1994 to 67.53% in 2015, indicating a diminishing awareness of the importance of renewable energy in the region. However, the dilemma arises as fossil fuels remain crucial for the economic development of the region. It becomes imperative to understand whether the shift to renewable energy has a positive or detrimental impact on economic growth in SSA.

Studies investigating the relationship between renewable energy and economic growth have been conducted in numerous countries, yet the findings remain inconclusive. While some studies reveal a positive association, others argue for a negative one. Unfortunately, research in this area is not well-developed in African countries. Among studies focusing on African nations, some, like Qudrat-Ullah and Nevo (2021), Saba (2023), and Gyimah et al. (2022), report a positive relationship between renewable energy and economic growth. Conversely, a study by İnal et al. (2022) suggests a negative relationship for the same region.

Moreover, studies in other regions also provide diverse insights. For instance, Wang et al. (2022) find a positive impact of renewable energy on economic growth in OECD countries. AlNemer et al. (2023) report a positive association in the case of Saudi Arabia, while Minh and Van (2023) find a positive impact in Vietnam. On the contrary, Tariq et al. (2023) reveal a negative relationship when investigating China's Belt and Road Initiative (BRI) countries. Additionally, another study by Wang et al. (2022) reports an insignificant association between renewable energy and economic growth. In summary, the overall findings regarding the impact of renewable energy on economic growth remain mixed and vary across different countries and regions.

Given the mixed findings in the literature, as stated above, coupled with the dearth of research on the topic in the case of SSA and the pressing environmental degradation in the region, there is a compelling motivation to understand the role of renewable energy in SSA's economic development. Therefore, this study aims to investigate the impact of renewable energy on economic growth in Sub-Saharan African countries, particularly amidst the increasing role of ICT in the region. Understanding the impact of renewable energy on SSA economies and identifying the factors behind this impact is considered essential information for both academics and policymakers. Thus, the objective of this study is to determine whether renewable energy is a significant beneficial factor that can promote economic growth in the region. If it is, the study aims to explore whether governments should prioritize the development of renewable energy in the region. This research is particularly timely given the growing importance of ICT in the area, adding an additional dimension to the investigation.This study incorporates 43 African countries as sample, ranging from Angola to Zimbabwe with the sample period of 2005–2022. The dependent variable in the study is economic growth, which is proxied by real GDP growth. The key independent variable is renewable energy consumption and two control variables entering the estimation are ICT (information, communication, and technology) and globalization.

The relationship among renewable energy, ICT, and globalization has been empirically supported (see, for example, Saba et al. (2023), Saba and Biyase (2022), Saba and Ngepah (2022a), and Saba and Ngepah (2022b). In estimating the model, this study employs the Pooled Mean Group (PMG) technique and presents several findings. First, based on our estimation, it is found that renewable energy does not contribute to economic growth in the region, both in the short and long run. Furthermore, the study also demonstrates that ICT does not impact economic growth in the region in the short run, but it positively affects economic growth in the long run. Finally, our estimation reveals that globalization has a positive and significant impact in the long run. However, the impact of globalization on economic growth in the short run is insignificant.

We identified several gaps in the existing literature on renewable energy and economic growth in Sub-Saharan Africa (SSA). First, there is a persistent inconsistency in findings regarding the impact of renewable energy on economic growth, particularly in the context of ICT and globalization in SSA as a whole. The scarcity of studies specifically investigating this intersection is notable. Second, the literature on ICT lacks consensus on the most representative proxy due to its multifaceted nature. Similarly, globalization is often categorized into financial or trade dimensions, further complicating the understanding of its impact. Consequently, the sign and magnitude of the impact of ICT on economic growth are susceptible to the choice of proxy. Addressing this vulnerability calls for studies to design comprehensive constructs rather than relying on single variables. Third, the interplay between ICT, renewable energy, and globalization is crucial. However, few studies have simultaneously investigated these three variables. Notable exceptions include studies by Sucharita et al. (2022), Appiah-Otoo and Song (2021), and Awad and Albaity (2022). This underscores the need for more research that considers the synergistic effects of ICT, renewable energy, and globalization on economic growth in SSA.

This study innovatively addresses the gaps identified in past literature in several ways. Firstly, recognizing the mixed findings on the impact of renewable energy on economic growth, we offer a fresh perspective by utilizing different proxies for ICT, renewable energy, and globalization. Additionally, we employ the Pooled Mean Group (PMG) methodology, which, to the best of our knowledge, has not been implemented in understanding the interplay between renewable energy, ICT, and globalization in the SSA region. This novel approach aims to enrich the existing literature on the relationship between renewable energy and economic growth in SSA. Secondly, acknowledging the susceptibility of the impact's sign and magnitude to the choice of proxy for ICT, globalization, and renewable energy, we adopt more comprehensive proxies to mitigate vulnerabilities. For instance, in the case of ICT, our study, while drawing inspiration from Appiah-Otoo and Song (2021) and Awad and Albaity (2022), diverges by developing a more intricate ICT proxy through Principal Component Analysis (PCA). This novel approach aggregates 12 different measures of ICT indicators, an unprecedented step in previous studies. Furthermore, our study, akin to Haldar et al. (2023) in terms of sample and methodology, defines globalization using the KOH globalization index instead of the financial globalization index used by Haldar et al. (2023). Lastly, building on the approach of Saba (2023), this study, instead of using militarization, introduces ICT and globalization as additional factors influencing the relationship between renewable energy and economic growth.

This study makes significant contributions to the literature on renewable energy and economic growth in several ways. Firstly, to the best of our knowledge, there is a scarcity of studies specifically investigating the impact of renewable energy on economic growth in the context of ICT and globalization in Sub-Saharan Africa (SSA) as a whole. Therefore, this study is among the few providing insights into this topic for the SSA region. Given the persistent issues of energy and economic growth in the SSA economy, our study offers valuable recommendations to policymakers and academics regarding the potential development of renewable energy, ICT, and globalization to catalyze economic growth. Secondly, in terms of methodology, our study contributes by employing the Pooled Mean Group (PMG) methodology. This approach allows us to reveal the impact of renewable energy on economic growth in SSA at both the regional and individual, country-specific levels. We believe that presenting results at both levels of analysis enhances the comprehensiveness of our findings. Finally, this study contributes theoretically to the literature on renewable energy and economic development by providing additional evidence regarding the impact of renewable energy on economic growth in the presence of ICT and globalization effects in the SSA region.

This study is structured as follows. The first section introduces the research context, outlines the gaps in the existing literature, and formulates the research questions. The second section presents a systematic literature review, offering a comprehensive examination of past research on renewable energy, economic growth, ICT, and globalization. The third section details our research methodology and presents the analysis of the impact of renewable energy on economic growth in the context of ICT and globalization. The final section summarizes our key findings, discusses their implications, and concludes the study.

2 Literature review

This study centers on the interplay of economic growth, renewable energy, globalization, and ICT development. While each of these variables individually contributes to a country's economic growth, we take a unique approach by simultaneously incorporating them into the same model. This is driven by empirical evidence demonstrating correlations among ICT, renewable energy, and globalization. Several studies, such as Saba, Djemo, Eita, Ngepah (2023), Akadiri et al. (2023), Saba and Biyase (2022), Saba and Ngepah (2022a, b, Akadiri and Adebayo (2022); Usman et al. 2020, 2022; Alola and Saint Akadiri (2021); Saint Akadiri et al. (2020); Alola et al. (2019a; b), have shown the correlation among ICT, renewable energy, and globalization. Given this close interconnectedness, our study acknowledges the need to understand the impact of each variable on economic growth inseparably, recognizing their interdependence.

There exists a body of literature exploring the impact of the three key variables—renewable energy consumption, renewable energy development, and ICT—on economic growth. Renewable energy consumption and development are inherently linked, with the former showing promise to induce the latter. Conversely, the effectiveness of renewable energy development for economic growth is contingent on its consumption. Consequently, much of the literature on renewable energy development is intertwined with that of renewable energy consumption.

Furthermore, some studies delve into the relationship between ICT and economic growth, as well as the connection between renewable energy and economic growth. The following subsections present an overview of past literature addressing the relationship of each of these three key variables concerning economic growth.

2.1 Renewable energy and economic growth

Theoretical considerations suggest that renewable energy consumption can have both positive and negative impacts on a country's economic development. A positive impact may manifest through the production channel, where renewable energy consumption reduces pollution, enhances environmental quality, and ensures more abundant natural resources for firms to bolster production. This abundance of resources, notably capital, can lead to increased production, thereby accelerating economic growth. Conversely, a negative impact can occur through the production cost channel. The utilization of renewable energy tends to elevate production costs, subsequently reducing production levels and decelerating economic growth. Despite numerous studies investigating the impact of renewable energy consumption (i.e., renewable energy) on economic growth across various countries and methodologies, the findings in this area remain mixed.

For instance, studies such as Qudrat-Ullah and Nevo (2021) argue for the positive and significant impact of renewable energy on economic growth. Their investigation focused on African countries and considered the presence of an environmental sustainability factor. The study's sample comprises 37 African countries, including Hong Kong, China, and Macao, for the period 2008–2014. GDP is utilized as the proxy for economic growth, serving as the dependent variable, while independent variables include renewable energy consumption and carbon emissions. Additionally, control variables, such as gross fixed capital formation, labor force, and access to electricity, are incorporated. The study employs the Granger causality test, revealing a unidirectional causality running from renewable energy consumption to economic growth, but not vice versa. Furthermore, utilizing the GMM estimation method, the study demonstrates that renewable energy consumption is statistically significant and has a positive impact on economic growth, both in the short and long run.

Saba (2023) investigated the nexus of renewable energy consumption, economic growth, and carbon emissions in the case of South Africa for the sample period of 1960–2019. The study employed real GDP as the proxy for economic growth, while renewable energy consumption was expressed as the share of total final energy consumption. Notably, Saba (2023) introduced militarization as one of the control variables. Using the dynamic ARDL approach, the study revealed a long-run equilibrium among renewable energy consumption, economic growth, carbon emissions, and militarization. In the long run, renewable energy consumption was found to have a positive and significant impact on economic growth. Interestingly, the study also demonstrated a bidirectional relationship between renewable energy consumption and economic growth. In other words, in the long run, economic growth positively affects renewable energy consumption. However, the study noted that the impact of renewable energy consumption on economic growth in the short run was not significant, which contrasts with the findings of Qudrat-Ullah and Nevo (2021). This divergence was attributed to the low usage of renewable energy in the region.

Saba (2023) and Qudrat-Ullah and Nevo (2021) highlight the impact of environmental factors and militarization on the magnitude and direction of the relationship between renewable energy and economic growth. In a similar vein, Gyimah et al. (2022) investigated the relationship between renewable energy and economic growth, considering the additional influence of trade and foreign direct investment. Their study focused on Ghana for the period 1990–2015, with economic growth approximated using the annual growth of constant GDP and renewable energy consumption as the independent variable. Through the Granger causality test and the mediation model, the study revealed a positive impact of renewable energy consumption on economic growth. However, it did not find an indirect effect from renewable energy consumption to economic growth. This finding supports a unidirectional relationship from renewable energy to economic growth, aligning with the results presented by Saba (2023).

AlNemer et al. (2023) explored the association between renewable energy and economic growth within the context of environmental quality in Saudi Arabia. Economic growth was approximated using GDP per capita, and environmental quality was assessed using carbon emissions. The study employed the spectral Granger causality approach and Wavelet tools, specifically the wavelet coherence analysis and multivariate wavelet, as the primary methods of analysis. Based on their estimations, the study demonstrated that renewable energy consumption positively influences economic growth in Saudi Arabia, aligning with results from Saba (2023) and Qudrat-Ullah and Nevo (2021). Notably, the study went beyond the economic aspect, revealing that renewable energy consumption also positively contributes to environmental quality in the country. Consequently, the study encourages Saudi Arabia to promote renewable energy as a viable substitute for fossil fuels.

In the case of Vietnam, Minh and Van (2022) investigated the relationship between renewable energy consumption and economic growth during the period 1995–2019. Economic growth, proxied by real GDP, was the key dependent variable, while renewable energy consumption, along with capital and labor, served as the primary independent variables, akin to the study by Shahbaz et al. (2020). Notably, in Minh and Van's study, renewable energy consumption was approximated using the amount of energy consumption (in quadrillions of British thermal units) rather than an index, as in Shahbaz et al. (2020). Using the Autoregressive Distributed Lag model (ARDL) for estimation, the study revealed that renewable energy consumption significantly and positively influences economic growth in both the short and long run. Additionally, the study demonstrated the existence of unidirectional causality from renewable energy to economic growth in Vietnam.

However, another study reports a negative impact of renewable energy consumption on economic growth in Africa. For example, İnal et al. (2022) examined the nexus of renewable energy and carbon emissions on economic growth in case of ten African oil-producing countries from 1990 to 2014. The ten sample countries include Angola, Algeria, Congo Republic, Nigeria, Equatorial Guinea, South Sudan, Libya, Sudan, and Gabon. The study applied the second-generation panel data regression, namely, the bootstrap panel LM cointegration technique, and demonstrates that the impact of renewable energy consumption on economic growth is diverse across countries. However, the study shows that renewable energy consumption is statistically significant and negatively affects economic growth in Angola, Sudan, Algeria, and the Congo Republic. Furthermore, unidirectional causality is found running from renewable energy consumption to economic growth in Algeria, Guinea, and Sudan.

Another negative relationship is also found in Tariq et al. (2023) who examined the relationship between economic growth and renewable energy consumption in case of China for 2000–2020. Specifically, the sample include China's Belt and Road Initiative (BRI) countries. Similar to Gyimah et al. (2022), the influence of trade and foreign direct investment is incorporated in the model as one feature in the model. Furthermore, the relationship between economic growth and renewable energy consumption is also examined amid the presence of economic globalization. The dependent variable in the study is renewable energy consumption, while the key independent variable is economic growth, which is approximated using GDP per capita growth. Using the Pooled Mean Group (PMG) ARDL estimation, the study demonstrates that economic growth and renewable energy consumption are negatively correlated in some BRI regions in the short run, but it is positively correlated in the long run. The negative relationship might occur because high development progress on China BRI project utilizes non-renewable energy intensively, instead of using renewable energy. Hence, the more progressive the project is, the use of fossil energy increases relative to renewable energy.

Huang et al. (2022) explored the nexus of renewable energy, ICT, globalization, and economic complexity in the case of E7 and G7 countries with the sample period between 1995 and 2018. From its model structure, Haseeb, Usman, and Ozturk (2022) is very close to our study, except One distinctive feature that this study offers is the use of economic complexity index as a proxy of economic growth. Furthermore, ICT is approximated using a PCA index, renewable energy use is proxied using the share of total final energy use, and globalization is approximated as financial development. Based on the correlational analysis, the study demonstrates that in case of E7 countries, renewable energy consumption, and economic complexity index are negatively correlated. Furthermore, the study also shows that ICT is positively correlated with the economic complexity index. Similarly, in the case of G7 nations, renewable energy consumption is also negatively correlated with economic growth. Likewise, ICT is also positively correlated with economic growth in the case of G7 countries.

Saba (2023), Qudrat-Ullah and Nevo (2021), İnal et al. (2022), Tariq et al. (2023) utilize single country as a sample to identify the relationship between renewable enegy and economic growth. Other studies are also interested to investigate the relationship in a global scale in a context of panel countries sample. For example, Shahbaz et al. (2020) examined the linkage between renewable energy consumption and economic growth using a sample of 38 renewable energy-consuming countries from 1990 to 2018. Economic growth in the study is approximated using real GDP per capita, which is a dependent variable, while independent variables in the study are renewable energy consumption, non-renewable energy consumption, capital, and labor. As a proxy of renewable energy consumption, the study utilizes the Renewable Energy Country Attractiveness Index (RECAI), constructed by Ernst and Young. Using panel regression, the study demonstrates that renewable energy consumption has a positive impact on economic growth both in the short and long run for the half of sample countries. This study shares similar results with Hieu and Mai (2022). Hieu and Mai (2022) focuses on 80 countries across different income levels to reveal the relationship by also featuring tax and subsidy effects in the model. Using the sample period between 1990 and 2020 and based on method of moment quantile regression (MMQR), the study demonstrates that renewable and non-renewable energy consumption positively affect economic growth in developing countries both in the short and long run.

Not only environmental or trade variables, the relationship between renewable energy and economic growth is also affected by country risk, which related to social and political environment. This is demonstrated by Wang et al. (2022) through their study about the impact of renewable energy consumption on economic growth across different countries' risks. Country risk is the main feature in the model, which covers political and financial risks. The sample of the study is OECD countries for 1997–2015. The study demonstrates that the impact of renewable energy consumption on economic growth based on country risks is different among countries. Considering the country risk, under a certain threshold of risk value, renewable energy consumption hurts economic growth. However, above the threshold, the study shows that renewable energy consumption is statistically significant and positively affects the economic development of the region. However, the study also demonstrates that, for some countries, no significant impact is found between renewable energy and economic growth. This finding contributes to the literature that, although many studies demonstrate a positive relationship, insignificant relationship between renewable energy and economic growth exists.

For instance, Haldar et al. (2023) investigated the impact of renewable energy on economic growth in the context of the nexus among ICT, electricity, consumption, innovation, and renewable power generation on economic growth. The study uses a sample of 16 emerging markets from 2000 to 2018. The dependent variable in the study is economic growth which is proxied using GDP per capita, while the key independent variable is renewable power generation. Furthermore, the study also incorporates financial globalization using a proxy of the share of domestic credit to GDP amid some control variables such as R&D expenditure, trade, human capital, and electric power consumption. Based on the estimation approached by the two-step instrumental variable GMM (IV-GMM), the study demonstrates that renewable power generation has no significant impact on economic growth. On the other hand, ICT has a positive impact on economic growth monotonically and its impact is significant in lower and middle-income countries. However, the study shows that financial globalization negatively affects economic growth.

Renewable energy is also correlated with ICT. Hence, interacting renewable energy and ICT relative to economic growth is considered essential. For example, the study from Saba and Biyase (2022) also interact renewable energy and ICT in their model. Specifically, they investigated determinants of renewable electricity in case of European countries. The sample includes 35 European countries over the period of 2000–2018. The dependent variable is renewable electricity output, which is approximated by the share of total electricity output. As for explanatory variables, Saba and Biyase (2022) use multiple variables from various dimensions covering macroeconomic variables, ICT variable, socio-economic variables (carbon emissions, land area, and population), and governance indicators (control of corruption, political stability, government effectiveness, regulatory quality, rule of law, voice and accountability). ICT in the study is composed by three indicators including mobile cellullar telephone subscriptions, fixed telephone subscriptions, and percentage of individuals using the internet, which are aggregated using principal component analysis. Moreover, the study also applies PCA to construct institutional quality variable. Using panel regression the system-generalized method of moments, the study demonstrates that most determinants have bidirectional relationship with renewable electricity. This finding thus confirms a relationship between renewable energy and ICT and suggests that when trying to understand the impact of renewable energy on economic growth, involving ICT as additional control variable should be considered essential.

In conclusion, findings in the area of the relationship between renewable energy and economic growth are mixed. Although most studies demonstrate a positive impact of renewable energy on economic growth, some other studies demonstrate a negative association, such as İnal et al. (2022) and Tariq et al. (2023), among others. Furthermore, another study also reports an insignificant association between renewable energy and economic growth, such as reported by Wang et al. (2022).

Therefore, it can be concluded that the association between renewable energy and economic growth is dependent on the country's characteristics where the association in each country or region may provide different results. In comparison to the studies mentioned above, in terms of sample and methodology, our study is close to Saba (2023), except instead of using militarization, we use ICT and globalization as other additional factors affeting the relationship between renewable energy and economic growth.

2.2 Globalization and economic growth

Theoretically, globalization can affect economic growth in a positive or negative way. On one side, globalization can impose positive externality through the channel of consumption. For example, the weakening of foreign currency can stimulate consumption on imported goods in a local economy. Given consumption as part of economic growth equation, the increased consumption then increases economic growth. However, on the other hand, a negative globalization shock can also affect local economy adversely. For example, global financial crisis affects another country through stock market, reduces households income and their ability to purchase. Consequently, consumption declines and eventually reduces economic growth, everything else constant. Hence, incorporating globalization in an economic model is an essential component to understand the relationship among variables as a whole.

Yang et al. (2022) investigated the relationship between renewable energy consumption and economic growth in the case of the Next Eleven countries (N-11) during the period of 1990–2020. The N-11 countries include some emerging markets that potentially become the world's largest economies, which include Egypt, Indonesia, Iran, Mexico, Bangladesh, Turkey, Pakistan, Nigeria, Vietnam, the Philippines, and South Korea. The study features globalization as one of control variables in the model, which is approximated by globalization index. In addition to globalization, the study also features the model with human development index and industry value added. The dependent variable is economic growth, which is approximated using constant real GDP, while the key independent variable is renewable energy consumption approximated by the share of total final energy consumption. Using the method of moments panel quantile regression, the study demonstrates that renewable energy has a positive impact on economic growth only in the short run, while it is insignificant in the long run. On the contrary, the study also demonstrates that globalization decreases economic growth.

Similar finding is also found in Haldar et al. (2023) investigated the impact of renewable energy on economic growth in the context of the nexus among ICT, electricity, consumption, innovation, and renewable power generation on economic growth. The study uses a sample of 16 emerging markets from 2000 to 2018 and defines globalization as financial globalization instead of as political variable. The dependent variable in the study is economic growth which is proxied using GDP per capita, while the key independent variable is renewable power generation. Furthermore, the study also incorporates financial globalization using a proxy of the share of domestic credit to GDP amid some control variables such as R&D expenditure, trade, human capital, and electric power consumption. Based on the estimation approached by the two-step instrumental variable GMM (IV-GMM), the study demonstrates that financial globalization negatively affects economic growth, which echoes the finding from Yang et al. (2022).

Unlike Yang et al. (2022) and Haldar et al. (2023), Tariq et al. (2023) shows a contrasted results. They examined the relationship between economic growth and renewable energy consumption in the case of China's Belt and Road Initiative (BRI) countries for 2000–2020 and incorporate globalization as one of control variables, in addition to trade openness and foreign direct investment. The dependent variable in the study is renewable energy consumption, while the key independent variable is economic growth, which is approximated using GDP per capita growth. Furthermore, globalization in this study is approximated using the share of credit to GDP. Using the PMG ARDL estimation, the study reveals that globalization significantly increases renewable energy consumption. This finding indicates that globalization has a positive indirect effect on economic growth through renewable energy consumption, which contradicts that of Yang et al. (2022) and Haldar et al. (2023).

Some studies also interact globalization with ICT and renewable energy. For example, Saba, Djemo, Eita, Ngepah (2023) investigated the role of ICT on environmental sustainability in the presence of renewable energy sources, agricultural, industrialization and institutional quality in case of African countries. In their study, globalization is measured using industrialization, and ICT is composed of of mobile celullar telephone subscriptions, fixed-telephone subscriptions, and percentage of individuals using internet, where all is aggregated into a single index using principal component analysis (PCA). As for renewable energy, the study uses renewable electricity output and renewable energy consumption. Using 51 African countries over the period of 2000–2021 as sample, the study demonstrates that coordination between ICT and renewabe energy sources can accelerate environmental sustainability in the region. In terms of the model structure, our study also interacts ICT, renewable energy sources, and globalization, but we use the interaction to understand their impact on economic growth, not on environmental quality (carbon emissions). This finding thus suggests that when trying to understand the impact of globalization on economic growth, involving renewable energy and ICT as additional control variable is considered important.

In conclusion, not many studies have incorporated renewable energy and globalization simultaneously in the same model. Some studies define globalization as economic openness, while others define it in terms of financial development. However, findings concerning the relationship between globalization and economic growth are also mixed. Some studies argue a positive association between the two, as presented by Tariq et al. (2023) and Huang et al. (2022), while some others argue negatively, as presented by Yang et al. (2022) and Haldar et al. (2023). Thus, not only by country, the association between globalization and economic growth is also dependent on the definition of globalization itself. In terms of the model structure, Haldar et al. (2023) is very close to our study. Haldar et al. (2023) interacts ICT, renewable energy, globalization and economic growth in their model. However, our study uses different measures for some of the variables. For example, instead of using financial globalization index, we define globalization more generally by using KOH globalization index.

2.3 ICT and economic growth

Theoretically, information and communication technology (ICT) should impose positive impact on economic growth through the channel of productivity. As Solow growth model explains, total output is positively correlated with total factor productivity. ICT provides more room for TFP to increase, which hence increases economic growth. The raise of productivity increases economic growth through multiple channels, including firms, labour or households. From production side, the improvement of ICT in production technology can increase marginal production, which enables firms to produce at greater quantity, and hence increase economic growth. Furthermore, from the perspective of labour, ICT can improve labour productivity since technology can help their work more efficiently. Finally, from households perspective, ICT can improve the way of purchase becomes more efficient (e.g. e-commerce, food delivery, etc.) which can increase their consumption and accelerates economic growth. Some studies have investigate the possibility of these channels.

No consensus regarding the best indiactor to represent ICT. Hence, the variation of ICT indicators in this area can be differentated based on the proxy of ICT. Some studies have elaborated the impact of ICT on economic growth. For example, Ze et al. (2023) examined the impact of ICT and financial globalization on economic growth in case of G10 countries for 1992–2020. ICT in the study is approximated by the share of individuals using the internet relative to the total population. Furthermore, economic growth in the study works as the dependent variable and is approximated using GDP. The study applies Cross-sectional autoregressive distributed lag (CS-ARDL) to investigate the relationship and demonstrates that financial globalization is positively significant in affecting economic growth in the sample individual countries. Furthermore, the study also demonstrates that ICT is also statistically significant in affecting economic growth at the regional level, and it is also valid in the long run.

Similarly, Bakry et al. (2023) investigated the relationship between ICT and economic growth in case of 27 countries from 1990 to 2019. The sample used in the study is at the top of the ICT development index. Economic growth in the study is approximated using per capita GDP, while two ICT variables used in the study are mobile cellular subscriptions (mobile) and the share of individuals using the Internet relative to the total population (Internet). In addition, the study also incorporates electric power consumption and trade openness, and control variables and employs the panel nonlinear autoregressive distributed lag (NARDL) as the estimation approach. The study demonstrates that ICT has a significant and positive impact on economic growth in the long run for the countries in the sample. Countries may also require time to reap benefits from ICT investments.

At the greater scale, Saba and Ngepah (2021) also investigated the nexus of ICT, economic growth and industrialization in case of global countries. The sample involves 171 countries during the period of 2000–2018, consisting of 25 low income countries, 41 lower middle income countries, 48 upper middle income countries and 57 high income countries. Specifically, the study explores whether there is a long run and causal relationship between ICT and economic growth by paying attention to the role of ICT diffusion in promoting industrialization across all income groups of the sample countries. Using panel causality test, the study demonstrates a unidirectional casuality from ICT diffusion to economic growth across all income groups. Furthermore, based on panel VAR analysis, the study demonstrates that ICT has a positive impact on economic growth but negative impact on industrialization. Findings from Saba and Ngepah (2021), confirms the finding from Ze et al. (2023) in terms of the positive impact of ICT on economic growth. However, Saba and Ngepah (2021) further explore that the positive impact occurs unidirectionally from ICT to the growth, not vice versa.

In the case of South Asian countries, Usman, Ozturk, Hassan, Zafar, and Ullah (2021) also examined the impact of ICT on the economic performance of the countries in the region from 1990 to 2018. In their study, ICT is approximated using mobile cellular subscriptions per 100 people, combines with the number of internet users per 100 people, which is similar to Ze et al. (2023). The countries analyzed are India, Pakistan, Sri Lanka, and Bangladesh. Economic growth in the study is a dependent variable and it is measured using per capita GDP. Like Bakry et al. (2023), Usman et al. (2021) also incorporated some control variables such as electric power consumption and trade openness, and implemented ARDL bounds testing and ECM approach to reveal the relationship. Based on the analysis, the study demonstrates that the positive impact of ICT on economic growth in the short run is only observed in Bangladesh and India. However, in the long run, the positive impact of economic growth is only observed in India, which contradics the finding from Bakry et al. (2023).

Instead of using a single ICT proxy relying on internet only as in Ze et al. (2023) or Usman et al. (2021), Fernández-Portillo, Almodóvar-Gonzales, and Hernández-Mogollón (2020) utilized the aggregated ICT proxy that is composed of multiple dimensions in investigating the impact of ICT on economic growth for 27 OECD countries for the sample period of 2014–2017. In the study, ICT indicators are derived from The Digital Economy and Society Index (DESI) which measures the ICT index by five dimensions of connectivity, human capital, internet use, technological integration, and public services. On the other hand, economic growth is approximated using three variables of GDP, namely, 2010 constant GDP, GDP per person employed (current price), and GDP per person employed (constant price). Based on the estimation using Partial Least Squared (PLS) methodology, the study demonstrates that the development of ICT positively increases economic growth in the region for the developed European economies, which is similar to the findings of the previous studies. However, the study also reveals that not all ICT indicators are statistically significant in affecting economic growth, indicating that investment in ICT should be selective and focused only on growth-inducing ICT indicators by also paying attention to the cost-benefit of the ICT investment.

Ze et al. (2023) shows an insightful finding demonstrating that the quality of relationship between ICT and economic growth may be affected by the proxy of ICT itself. Based on Appiah-Otoo and Song (2021), among the ICT indicators used, fixed telephone lines have the greatest impact on economic growth, followed by mobile phones. However, based on non-linear investigation, the impact of ICT on economic growth is significant and positive across all country groups in the short run, including lower-income countries.

Similar to Fernández-Portillo, Almodóvar-Gonzales, and Hernández-Mogollón (2020), Awad and Albaity (2022) also examined the relationship between ICT and economic growth using a single ICT index. The study is explored in case of 44 countries in the Sub-Saharan Africa region for 2004–2020. Economic growth in the study is presented by GDP growth as a dependent variable, while the ICT in the study is measured using the ICT index derived from the African Development Bank database. Furthermore, the study also includes some control variables such as FDI, investment, inflation, trade openness, education, and political rights. The study applied the panel-corrected standard errors (PCSE) and two steps GMM on the sample and demonstrates some findings. First, the study demonstrates that ICT positively and significantly affects economic growth in the SSA region. The study demonstrates that ICT can accelerate economic growth through the channel of time and cost reduction related to transit. In addition to ICT, the study also demonstrates that FDI, trade openness, and investment also contribute to economic growth in the region.

Although previous studies confirm the positive impact of ICT on economic growth, non of them explore to which industry or sector the positive impact is. Nguyen and Doytch (2022) accomodate the question by exploring the impact of ICT on economic growth in the global sample over the period 1998–2016. This study features the presence of a number of patents in which ICT in the study is approximated using the number of patents, which is derived from PATSTAT global, and this works as the key independent variable. The sample consists of multi-development countries, consisting of 26 developed countries and 17 emerging economies. The dependent variable used in the study is economic growth, which is approximated using real GDP annual growth, real GDP per capita growth, and growth in service sectors. Based on the Granger causality test, the result demonstrates that, among a number of sectors explored, no significant impact of ICT on economic growth in the manufacturing sector. Furthermore, the study demonstrates unidirectional causality running from ICT patents to economic growth (i.e., real GDP growth, real GDP per capita growth, and service sector growth), which shares the findings from Saba and Ngepah (2020). On the contrary, no significant Granger causality is identified from economic growth to ICT patents.

Another question raised from the impact is whether the positve impact of ICT on economic growth occurs universally across different income groups or whether it only occurs on rich countries. Appiah-Otoo and Song (2021) investigated such issue by comparing the impact of ICT on economic growth between rich and poor countries. The study involves 123 countries covering rich and poor countries from 2002 to 2017. The 123 countries consist of 45 high-income, 58 middle-income, and 20 low-income countries. In the study, economic growth is measured using GDP per capita, while ICT is measured using the composite index of mobile, internet, and fixed broadband which is built using principal component analysis. The ICT PCA-related variables include internet users to the total population, the number of mobile cellular per 1000 people, mobile cellular subscribers per 100 people, and the number of fixed broadband subscribers per 100 people. Based on the IV-GMM model estimation, the study demonstrates that ICT has a significant and positive impact on economic growth in countries across all development levels: high-income, middle income and low-income countries. However, although statistically significant across all development levels, the magnitude impact of the overall ICT index on economic growth is the largest in medium-income countries, followed by low-income countries, and high-income countries.

However, some findings from Appiah-Otoo and Song (2021) are not necessarily guaranteed from the view of Albiman and Sulong (2017). According to Albiman and Sulong (2017), although the impact of ICT on economic growth is positive in the short run, the study shows that the impact is negative in the long run for lower- and upper-income countries but is positive for lower-middle countries. Also, the study demonstrates that ICT has a positive and significant impact on lower-middle and upper-middle income countries in the short run, but it is insignificant for the case of lower-income countries. Albiman and Sulong (2017) concluded these findings for the case of Sub-Saharan African (SSA) region for 24 years from 1990 to 2017 in both linear and non linear fashion. The dependent variable in the study is economic growth, which is approximated using GDP per capita. On the other hand, ICT in the study is proxied by four indicators, namely, fixed telephone lines, mobile phone subscriptions, internet subscriptions, and the sum of both fixed telephone lines and mobile phone subscriptions. The non-linear model is presented by including the square term of the ICT variables and estimated by Pooled mean group (PMG) and Mean Group (MG).

Some literature have also interacted ICT with renewable energy, indicating the close connectedness between the two. For example, Saba and Ngepah (2022a) also reveal a close association between ICT and renewable energy. They investigated a similar study in a greater sample beyond European countries. Their study investigates the presence of convergence in renewable energy sources and how their dynamics with respect to the convergence. The study covers 183 countries in the same period of 2000–2018. In addition, the study utilizes multiple dependent variables, namely, renewable electricity ouput as a share of total electricity output and renewable energy consumption as a share of total final energy consumption. All explanatory variables are similar to thpse in Saba and Biyase (2022), including the composed ICT. However, although the variables used are similar to those in Saba and Biyase (2022), Saba and Ngepah (2022) utilize different methodology known as convergence algorithm. Using the method, the study demonstrates that panel convergence of the determinants in renewable energy sources is absent. ICT is found being one of the determinants that drives the renewable energy sources convergence. Using the same sample and methodology (convergence algorithm), Saba and Ngepah (2022b) further investigates the determinants of convergence or divergence clubs for the regions. Using multinomial logit regression, the study demonstrates that the determinants of renewable energy consumption are essential for convergence club in each region. This finding thus suggests that when trying to understand the impact of ICT on economic growth, involving renewable energy as additional control variable is considered important.

In conclusion, findings in the area of the association between ICT and economic growth are also considered mixed, although a positive association dominates the findings. Some studies see a positive association between ICT and economic growth, such as those presented by Awad and Albaity (2022), Fernández-Portillo et al. (2020), and Appiah-Otoo and Song (2021), among others. However, others argue that the positive association is only valid in the short run but negative in the long run, as presented in Albiman and Sulong (2017). On the contrary, the opposite case where ICT positively affects economic growth in the long run but not significantly in the short run is also reported by Usman et al. (2021), among others. Finally, the study by Bello et al. (2023) and Nguyen and Doytch (2022) demonstrates that the significance of the association between ICT and economic growth is also dependent on the economic sector. In terms of sample countries, our study is close to Appiah-Otoo and Song (2021) and Awad and Albaity (2022), among others. However, our study is different from them in terms of ICT indicator developed. That is, we develop ICT in a more complex way based on PCA that aggregates 12 different measures of ICT indicators, which has not been done in previous studies.

3 Theoretical framework, data, and methodology

3.1 Theoretical framework

There exist four testable hypotheses on the relationship between energy consumption and growth as reported by Apergis and Payne (2011). First, the growth hypothesis emphasizes the direct and indirect role of energy consumption on growth. Second, the conservation hypothesis holds that energy conservation policies that limit energy use could be detrimental to growth. Third, the feedback hypothesis considers the complementary role of energy consumption and economic growth as each reinforces the other. Fourth, the neutrality hypothesis submits that energy consumption plays a negligible role in the growth process. The renewable energy-economic growth nexus has been shown to confirm the feedback hypothesis by Akadiri et al. (2019) in EU-28 countries. Drawing on Apergis and Payne (2011) and Akadiri et al. (2019), we specify a model for the role of renewable energy on economic growth in Sub-Saharan Africa. We include control variables like information and communication technology (ICT) and the index of globalization. Empirical evidence suggests that ICT enhances economic growth in developed, emerging, and developing economies (Niel, 2018; Stanley et al. 2018; Appiah-Otoo and Song 2021; etc.). Prior studies also report mixed outcomes on the role of globalization on economic growth (Ying et al. 2014; Gurgul and Lach 2014; Suci et al. 2016; Hassan et al. 2019).

Therefore, the following functional model specification indicates the role of renewable energy and relevant control variables on economic growth in Sub-Saharan African Countries.

$$RGPPC_{i,t} = f(ICT_{i,t}, RENEW_{i,t}, GLO_{i,t}) \tag{1}$$

To address the issue of heteroscedasticity, we undertake the logarithmic transformation of the variables and express the econometric form of the model in Eq. (2).

$$LNRGPPC_{i,t} = \gamma_0 + \gamma_1 LNICT_{i,t} + \gamma_2 LNRENEW_{i,t} + \gamma_3 LNGLO_{i,t} + \epsilon_{i,t} \tag{2}$$

Where RGPPC stands for real GDP per capita (a proxy for economic growth); ICT represents information and communication technology; RENEW indicates renewable energy consumption; and GLO represents an index of globalization.

3.2 Data and measurement

In this section, we discuss the data, measurement, and sources. To account for the role of renewable energy on economic growth, the study employed data on relevant variables for a panel of 43 Sub-Saharan African (SSA) Countries from 2005 to 2022, based on the literature review and data availability. Data on real gross domestic product per capita (measured in constant 2010 US dollars) and renewable energy (measured as the share of renewable energy in total energy consumption) were sourced from the World Development Indicators (WDI) of the World Bank. Following Bello et al. (2023), we derived the ICT diffusion index as a measure of ICT using Principal Component Analysis (PCA). The ICT diffusion index is based on twelve ICT indicators in line with the International Telecommunication Union (ITU) (see Table 1). Globalization index is sourced from the KOF Swiss Economic Institute database. The index, which encompasses economic, social, and political globalization, was developed by Dreher (2006) and revised by Dreher et al. (2008) and improved by Gygli et al. (2019).

3.3 Methodology

The study employs the Panel Autoregressive Distributed Lag Model (ARDL) to assess the role of renewable energy on economic growth in line with similar studies on the energy-growth nexus (Apergis and Payne 2011; Akadiri et al. 2019). Drawing on Pesaran et al. (1999), we re-write Eq. 2 in the form of the ARDL (p, q) model, indicating lagged dependent variables and lagged regressors.

$$LNRGPPC_{i,t} = \gamma_0 + \sum\nolimits_{r=1}^{p} \gamma_{i,r} LNRGPPC_{i,t-r} + \sum\nolimits_{r=0}^{q} \delta_{i,r} W_{i,t-r} + \epsilon_{i.t} \quad (3)$$

Table 1 ICT indicators

ICT indicators Source	Source
Secured Internet servers (per 1 million people)	WDI
Secure Internet servers WDI	WDI
individuals using the Internet (% of the population)	WDI
Mobile cellular subscriptions	WDI
Mobile cellular subscriptions (per 100 people)	WDI
Fixed broadband subscriptions (per 100 people)	WDI
Fixed telephone subscriptions	WDI
Fixed broadband subscriptions	WDI
Fixed telephone subscriptions (per 100 people)	WDI
Mean secondary school enrolment in years	WDI
Tertiary school enrolment (Gross)	WDI
Secondary school education (Gender parity)	WDI

Source: Adopted from Bello et al. (2023)

Where, $W_{i,t} = (LNICT_{i,t}, LNRENEW_{i,t}, LNGLO_{i,t})$ i=1, 2, 3,..., N indicates the cross-sectional units while t=1, 2, 3,..., T stand for the time dimension. $W_{i,t}$ is the vector of regressors. γ_0 represents the country-specific effect, while the coefficient of lagged dependent is shown by $\gamma_{i,r}$. The coefficient of lagged regressors is indicated by $\delta_{i,r}$.

The ARDL approach to cointegration is not only appropriate when the variables are stationary at level, first difference, or a mixed order of integration, but it also addresses issues like endogeneity bias. The ARDL technique estimates both short-run and long-run coefficients and is suitable for both small and large sample sizes.

The estimation procedure for the ARDL cointegration technique begins with the conduct of a unit root test to ensure that the level of stationarity of the variables is not beyond, the first difference, i.e., I(1). There are different panel unit root tests techniques in the literature, of which this study employs Levin et al. (2002), Im et al. (2003), the Fisher -ADF and Fisher -PP type (Maddala and Wu 1999), to investigate the stationarity properties of the macro panel data. Unlike individual unit root tests, panel unit root tests have been associated with higher power (Baltagi 2008).

The next step in the panel ARDL procedure is the conduct of a panel cointegration test to determine the existence of a long-run relationship among the variables in the economic growth model. The popularity of the cointegration test in the literature is hinged on the fact that economic hypotheses/theories are based on long-term relationships (Bekun and Akadiri 2019). Therefore, this study employs a battery of panel cointegration tests including the Fisher-type Johansen panel cointegration test, Pedroni's (1999) panel cointegration test, and Kao's (1999) panel cointegration test. The tests are based on the null hypothesis of no cointegration which when rejected, implies the existence of a long-run relationship among the variables in the model.

The error correction rendition of the ARDL model can be shown by re-writing Eq. 3 as:

$$\begin{aligned} \Delta LNRGPPC_{i,t} = \rho_i LNRGPPC_{i,t-1} - \beta_i W_{i,t} + \sum\nolimits_{r=1}^{p-1} \gamma^*_{i,r} \Delta LNRGPPC_{i,t-r} \\ + \sum\nolimits_{r=0}^{q-1} \delta^*_{i,r} \Delta W_{i,t-r} + \epsilon_{i,t} \end{aligned} \tag{4}$$

Where;

$$\rho_i = -\left(1 - \sum\nolimits_{r=1}^{p} \gamma_{i,r}\right), \beta_i = -\frac{\sum_{r=0}^{q} \delta_{i,r}}{(1 - \sum_{r=1}^{p} \gamma_{i,r})} = -\frac{\sum_{r=0}^{q} \delta_{i,r}}{\rho_i},$$

$$\gamma^*_{i,r} = -\sum\nolimits_{h=r+1}^{p} \gamma_{i,h} \text{and} \delta^*_{i,r} = -\sum\nolimits_{h=r+1}^{q} \delta_{i,h}$$

The first part of Eq. 4, $\rho_i(LNRGPPC_{i,t-1} - \beta_i W_{i,t})$, stands for the error correction term while the second part, $\sum_{r=1}^{p-1} \gamma^*_{i,r} \Delta LNRGPPC_{i,t-r} + \sum_{r=0}^{q-1} \delta^*_{i,r} \Delta W_{i,t-r}$ relates to the short-run component of the model. While ρ_i represents the error correction parameter, β_i is the long-run vector parameter of the regressors.

There exist some popular estimators for the panel ARDL model, including Mean Group (MG), Pool Mean Group (PMG), and Dynamic Fixed-Effect (DFE). However, this study dwells on the Pool Mean Group (PMG) estimator proposed by Pesaran et al. (1999) due to some salient features. First, the PMG estimator allows for the long-run coefficients to be homogenous while short-run coefficients and error variances are heterogeneous across cross-sections. Second, the PMG estimator is characterized by robustness and reliability when it comes to lag orders and outliers.

To test for the sensitivity of the long-run coefficients to alternative long-run panel estimation techniques, we employ the Panel Fully Modified OLS (FMOLS), Panel Dynamic OLS (DOLS), and Panel Quantile Regression. The FMOLS estimator is a non-parametric approach proposed by Pedroni (2000). The FMOLS is suitable for dealing with serial correlation and endogeneity bias. The Panel DOLS as advanced by Pedroni (2001) addresses similar issues as the FMOLS estimator but differs in the sense that it is parametric and applies both lagged and lead differences. The Panel quantile regression technique which resolves issues of outliers was developed by Koenker and Bassett (1978). It is used for the estimation of conditional median or other quantiles of the dependent variables given certain values of the regressors (Adebayo et al. 2022).

The next step in the methodology is the test for causality between real GDPs per capita and renewable energy, ICT, and globalization. The study employs the panel Granger causality test for heterogeneous non-causality developed by Dumitrescu and Hurlin (2012). The test is based on the vector autoregressive model and possesses asymptotic and semi-asymptotic distributions. The test is rooted in the assumption of heterogeneity and normal distribution (Eluwole et al. 2020).

We hereby present the specification of the model in its linear form:

$$z_{i,t} = \sum\nolimits_{r=1}^{R} \sigma_{i,}^{(r)} Z_{i,t-r} + \sum\nolimits_{r=1}^{R} \omega_{i,}^{(r)} H_{i,t-r} + \epsilon_{i,t} \tag{5}$$

Where R indicates the optimum lag length, $\sigma_{i,}^{(r)}$ represents the coefficient of the autoregressive term, while $\omega_{i,}^{(r)}$ depicts the coefficient of the regression which is assumed to change within the cross sections. Z denotes the dependent variable – real GDP per capita (RGPPC) while H represents a vector of independent variables. Causal relationships in heterogeneous models can be estimated by homogenous non-stationary hypothesis (HNC), where the null and alternative hypotheses are stated as:

$$H_0 : \omega_i = 0 \quad \forall_i = 1, \ldots, M$$

$$H_0 : \omega_i = 0 \quad \forall_i = 1, \ldots, M_1$$

$$\omega_i \neq 0 \quad \forall_i = M_1 + 1, M_1 + 2, \ldots, M$$

Where the unknown coefficient that satisfies the condition $0 \leq M_1/M < 1$is indicated by M_1. The ratio of M_1/M is expected to be always less than 1. However, there is no causality across the groups if M_1/M=1. Conversely, $M_1/M = 0$ suggests evidence of a causal relationship in the panel data model.

Table 2 Descriptive statistics

	GLO	ICT	RGPPC	RENEW
Mean	48.93851	0.048455	2235.409	65.23282
Median	48.57265	-0.485824	1041.653	77.18000
Maximum	72.21717	10.84453	16992.03	97.42000
Minimum	29.17424	-2.662841	263.3610	0.710000
Std. Dev.	7.892039	2.074288	2986.060	26.82187
Skewness	0.512328	2.339854	2.538598	-0.976357
Kurtosis	3.641168	9.968160	9.584407	2.747259
Jarque-Bera	41.82166	2016.772	1978.913	110.9783
Probability	0.000000	0.000000	0.000000	0.000000
Sum	33620.75	33.28843	1,535,726.	44814.94
Sum Sq. Dev.	42727.02	2951.633	6.12E+09	493517.0
Observations	687	687	687	687

Table 3 Correlation matrix

Probability	GLO	ICT	RGPPC	RENEW
GLO	1.000000			
ICT	0.341736	1.000000		
RGPPC	0.471030	0.055471	1.000000	
RENEW	-0.547432	-0.208294	-0.731713	1.000000

4 Empirical results and discussion

Results from the descriptive statistics are presented in Table 2 which provides useful information about the statistical properties of the variables, while the panel-based correlation matrix in Table 3 put on view the apriori information about the variables under investigation. The descriptive statistics show the Skewness, Kurtosis, and Jarque-Bera statistics among others. The panel-based correlation test show that the impact of globalization (GLO), renewable energy (RENEW), and information technology (ICT) is positive but insignificant. In the case of RENEW, real GDP per capita (RGPPC) had a negative and strong effect, GLO indicates a negative moderate correlation while ICT suggests a negative but insignificant.

We further performed the unit root test as presented in Table 4 to determine the stationary properties of the variables. This is to prevent a situation whereby variables of I(2) are estimated, resulting in spurious results. The result indicates that only GLO was stationary at I(0) at a 1% significant level, which implies the likelihood of a cointegrating relationship.

Following the mixed order of integration from our macro panel variables, we proceed to perform a cointegration test. Table 5 presents the Fisher-type Johansen cointegration test which reveals at most 5 cointegration equations, at a 1% significant level. Both Pedroni and Kao cointegration tests further validate the long-run relationship among the variables, which causes the rejection of the null hypothesis of no cointegrating relationship at a 1% significant level.

Afterward, we perform the Pool Mean Group (PMG) estimator and present the result in Table 6. The PMG estimator encompasses both the long- and short-run coefficients, as well as the error correction term (ECT) which represents the speed of

Table 4 Panel unit root tests

Variables	LLC	IPS	Fisher-ADF	Fisher-PP
Level				
LNFDI	-2.950***	-2.894***	130.650***	206.728***
LNGLO	-9.780***	-3.965***	149.821***	231.525***
LNRENEW	0.142	3.045	67.797	61.555
LNRGPPC	5.832	5.070	54.597	59.361
ICT	0.515	7.346	45.511	45.897
First difference				
LNFDI	-6.619***	-8.630***	240.662***	564.170***
LNGLO	-11.466***	-9.362***	248.671***	428.330***
LNRENEW	-11.414***	-8.288***	222.649***	402.328***
LNRGPPC	-8.157***	-6.1963***	202.158***	192.195***
ICT	-14.021***	-10.269***	272.410***	272.841***

Note: *** indicates stationarity at a 1% level of significance

Table 5 Fisher-type Johansen panel cointegration test

Number of cointegrating equations	Trace test	Maximum-eigenvalue test	
None	107.0***	83.46	
At most 1	1229.***	1088.***	
At most 2	685.2***	491.3***	
At most 3	317.2***	249.3***	
At most 4	189.3***	189.3***	
The p-value for rejecting the null hypothesis of no cointegration is at ***0.01 significance level (MacKinnon et al. 1999)			
Pedroni cointegration test results			

	Statistic	P-value	W-Statistic	P-value
Alternative hypothesis: common AR coefs. (Within-dimension)				
Panel v-Statistic	17.584***	0.000	7.945***	0.000
Panel rho-Statistic	5.776	1.000	5.838	1.000
Panel PP-Statistic	4.637	1.000	0.469	0.680
Panel ADF-Statistic	-0.184	0.426	-2.809***	0.003
Alternative hypothesis: individual AR coefs. (Between-dimension)				
Group rho-Statistic	8.194	1.000		
Group PP-Statistic	-0.657	0.256		
Group ADF-Statistic	-3.734***	0.000		

Kao cointegration test

	t-Stat.	P-value
ADF	2.208**	0.013
Residual variance	0.116	
HAC variance	0.167	

Note: *** and ** indicate stationarity at 1% and 5% levels of significance, respectively. HAC=heteroskedasticity and autocorrelation are consistent; ADF=Augmented Dickey-Fuller; PP=Philip Perron; AR=Autoregressive.

adjustment. As expected, the explanatory variables adjust to the long-run path by a degree of -0.031, indicating a significant level of 1%. This implies that deviation from the path of equilibrium can be corrected by 3%, annually when the explanatory variables are combined.

Table 6 PMG estimates of the ARDL (1, 1, 1, 1) model

Variable	Coefficient	Std. Error	t-Statistic	P-value
Long Run Equation				
ICT	-0.245***	0.022	-11.364	0.000
LNRENEW	-0.939***	0.055	-17.073	0.000
LNGLO	2.790***	0.061	45.924	0.000
Adjustment coefficient	-0.031***	0.008	-3.814	0.000
Short Run Equation				
ΔICT	0.032**	0.015	2.156	0.032
ΔLNRENEW	-0.436**	0.208	-2.102	0.036
ΔLNGLO	0.073	0.106	0.687	0.493
Number of observations	644			

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

Table 7 FMOLS, DOLS, and Quantile regression outcomes

	ICT	LNRENEW	LNGLO
FMOLS	-0.036*	-0.640***	2.500***
DOLS	-0.019*	-0.524***	2.372***
Quantile regression	0.024***	-0.595***	2.4122***

***and * indicate stationarity at 1% and 10% levels of significance, respectively

The result showed that all the explanatory variables are statistically significant in the long run. Both ICT and LRENEW hurt RGPPC with 0.25, 0.94, and 2.79%, in the long run (IRENA 2022). Specifically, it was observed that a 1% drop in ICT development is responsible for a 0.25% fall in RGPPC, however, the contribution of ICT is positive and significant in the short run, as a unit increase in ICT could raise RGPPC by 0.3%. This finding is consistent with Haftu (2019) who argued that ICT has failed to improve GDP per capita due to slow penetration, low ICT skills, and lack of local content in Sub-Sahara Africa (SSA). It is pertinent to note that SSA countries lack the resources to deploy modern technology as they rely on foreign direct investment which also depends on macroeconomic environment of the recipient country. The aggregate performance of the less developed countries in SSA may be responsible for the result in the short run.

The contribution of LRENEW to RGPPC was negative and significant by 0.94 and 0.44% both in the long and short run. It shows that a 1% fall in LRENEW would cause a 0.94 and 0.44% decline in economic growth both in the long and short run, respectively. This finding is contrary to Kouton (2021) and Lyeonov et al. (2019) who observe that an increase in renewable energy can raise GDP per capita by 5.6%. Despite the potential of renewable energy sources (solar, hydro, wind, and geothermal), renewable energy remains unaffordable for many households because of the high cost associated with production and installation.

The International Renewable Energy Agency (2022) reported that only 46% of the SSA population had access to electricity. Decrease in renewable energy consumption can reduce the total energy consumption, hence a fall in economic growth. The aggregate fall in individual contribution to the economy would affect the economic prospect of SSA. However, subsidizing renewable energy production can distort the market and increase the supply and consumption.

The result further shows a positive and significant relationship between LNGLO and RGPPC in the long run with 2.8% contribution, however, the impact was weak in the short run at 0.7%. The contribution of globalization shows that a 1% rise in globalization would raise RGPPC by 1% in the long run. This finding supports the work of Buysse et al. (2018) and Bataka (2019) who reported a long-run relationship between globalization outcomes and output among low-income countries of the SSA. Specifically, Bataka (2019) argued that trade policies (de jure) can improve economic growth while trade flows and activities (de facto) tend to undermine economic growth. In the period of tranquillity, globalization will enhance growth where there is an efficient allocation and utilization of resources.

The weak impact of globalization on economic growth in the short run could be traced to low access to technology, weak market structure, and low investment in SSA countries (Akadiri et al., 2020). Globalization enables economic prospects through efficient allocation of resources; however, the result is not surprising for SSA. The region is characterized by poor competitiveness and infrastructure development, high unemployment and unskilled workforce, political instability, and lack of access to technological innovation are factors that hamper growth, among others. The region is also characterized by trade deficit and large public debt occasioned by commodity price shocks which exacerbated the economic situation.

For a robustness analysis, the Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Quantile Regression are reported in Table 7. The DOLS is suitable for fractionally integrated variables I(0) and I(1) while accounting for endogeneity and small sample bias. Both the FMOL and DOLS validated the long-run relationship, and the impact of ICT on LNRGPPC are negative and statistically significant for the two model. The impact of LRENEW on LNRGPPC is also negative and statistically significant while LNGLO is positive and significant. The result for panel Quantile regression further shows that ICT and LNGLO have a positive link with LNRGPPC while LRNEW has a negative relationship with LNRGPPC.

Furthermore, a country-specific analysis is reported in Table 8. The empirical result presents the PMG short-run coefficient across the cross-sections. The result is presented in three categories. The result showed that renewable energy has a negative and significant impact on economic growth in 9 SSA countries (Angola, Chad, Comoros, Cote d'Ivoire, Equatorial Guinea, Guinea, Nigeria, Zambia, and Zimbabwe.) However, the impact was insignificant for Burkina Faso, Congo Dr., Gabon, Kenya, Mali, Niger, Nigeria, Sierra Leone, and Uganda. Notably, most of these countries are resource-rich countries.

This result is not surprising, given the infrastructural gap in the energy sector of SSA. Though the International Energy Agency (IEA) reported that renewable energy has increased in Africa since 2019 (IEA, 2023). For instance, the government of Angola has implemented the Angola Renewable Energy Program (AREP) since 2019, which has improved total energy production from 33 to 43% while renewable energy accounts for 64% of the total energy mix (AfDB 2023). Chad has a 6.4% rating of access to electricity, compared to 48% of the SSA countries; while less than

Table 8 PMG short-run coefficient across cross-sections

Regressors	ΔICT	ΔLNRENEW	ΔLNGLO	Adjustment term
Angola	0.043***	-204*	0.115	-0.0205***
Benin	0.016*	0.176***	0.236***	0.009
Botswana	-0.560***	-0.474	0.198	-0.030*
Burkina Faso	0.070***	-0.230	0.133*	-0.020
Burundi	-0.020***	0.074	0.285***	-0.143***
Cabo Verde	0.001	0.158*	-0.705	-0.131***
Cameroon	-0.006***	0.188**	0.294***	-0.036***
Central African Republic	0.050**	-4.474	-0.161	-0.060*
Chad	0.333***	-0.711**	0.148	-0.226***
Comoros	0.006***	-0.106***	0.064*	0.046***
Congo, Dem. Rep.	0.086***	-0.647	-0.037	-0.049***
Congo, Rep.	0.049***	0.405***	0.285	-0.237***
Cote d’Ivoire	0.038***	-0.601***	0.680	0.012**
Equatorial Guinea	0.002	-0.56***	-3.117	0.115***
Eswatini	-0.046***	0.139***	-0.99**	-0.064***
Ethiopia	-0.042***	1.195	0.470***	-0.024***
Gabon	0.100***	-0.108	-0.186*	-0.077***
The Gambia, the	0.320***	0.191***	-1.482**	-0.093***
Ghana	0.227***	0.427***	-0.247**	-0.499***
Guinea	0.050***	-0.337**	0.390**	0.142**
Guinea-Bissau	0.111***	0.654	-0.084**	-0.178***
Kenya	0.017***	-0.092	-0.325	-0.093***
Lesotho	-0.159***	0.008	0.378	-0.083***
Liberia	-0.011	0.120	0.407**	-0.205***
Madagascar	0.242***	0.393*	-0.077	-0.381***
Malawi	-0.003**	0.182**	0.382***	-0.071***
Mali	0.028	-0.065	0.220	-0.002
Mauritania	0.009***	0.047	0.048	-0.005
Mauritius	0.014***	0.246***	0.307	-0.078***
Mozambique	0.010***	0.114***	-0.196***	-0.121***
Namibia	-0.060**	0.163	-0.044	-0.340***
Niger	-0.009**	-0.0322	0.230**	-0.027***
Nigeria	0.038***	-0.531***	0.187	-0.153***
Rwanda	0.097***	0.119	-0.243***	-0.301***
Senegal	0.079***	0.045***	-0.152	-0.051***
Seychelles	-0.327***	0.107***	-0.843*	-0.016***
Sierra Leone	0.261***	-1.698	-0.314	-0.066***
South Africa	0.019***	0.059**	1.165**	-0.081***
Tanzania	-0.088*	0.213*	0.267	-0.050***
Togo	-0.139***	0.008	-0.513*	-0.079***
Uganda	0.116***	-0.878	-0.092	-0.169***
Zambia	0.057***	-0.325*	0.305	-0.072***
Zimbabwe	-0.022**	-0.2746*	-0.955	-0.057***

Note: ***, **, and * indicate stationarity at 1%, 5%, and 10% levels of significance, respectively

10% of the population has electricity (World Bank 2022). Nigeria's access to energy is extremely poor, as 71% of the population have no access to electricity despite the privatization of government-owned electricity companies and the decentralization of renewable energy (Weforum 2023). In Kenya, access to electricity was 75% in 2022, with geothermal been the major source of energy. The cost of renewable energy remains high as a result of 14% VAT charges on imported equipment for off-grid solar plants.

The result also showed that renewable energy has a positive and significant effect on 15 SSA countries (Benin, Cabo Verde, Cameroon, Congo, Eswatini, Gambia, Ghana, Madagascar, Malawi, Mauritius, Mozambique, Senegal, Seychelles, South Africa, and Tanzania). For instance, coal dominates South Africa's energy mix, with renewable energy contributing 7% while 84.4% of the population have access to electricity. Ghana produced 10% of renewable energy with 84% access to electricity. Cameroon and Malawi produced 73 (biomass) and 78% of renewable sources, respectively (Centurion 2022; IEA 2022). Mozambique is the largest producer of energy in Southern Africa, with hydropower representing 82% (68% biomass) of the total energy mix (Enerdata 2022).

However, the result was insignificant for Burundi, Ethiopia, Guinea-Bissau, Lesotho, Liberia, Mauritania, Namibia, Rwanda, and Togo, which suggests a weak impact of renewable energy (RENEW) on economic growth. This may be due to infrastructural gap in the energy sector, particularly renewable energy. For instance, Rwanda has one of the lowest per-capita electricity consumption with only 16% of the population having access to electricity while renewable energy constitutes 63% of the energy mix (AfDB 2013; IRENA 2022). Ethiopia generates 96% of hydropower with 45% accessibility and limited connection to the power grid. The country's energy generation is low as many rely on biomass fuels.

Following the estimation of Dumitrescu and Hurlin's model, the result is reported in Table 9. The Wald statistics indicate that economic growth Granger causes RENEW at a 1% significant level, which suggests a unidirectional causality running from economic growth to RENEW. This suggests that economic growth stimulates RENEW.

Table 9 Dumitrescu and Hurlin's panel dynamic causality test

Null Hypothesis	W-Stat.	Zbar-Stat.	P-Value	Causality
ICT≠LNRGPPC	5.286***	5.159	0.000	Yes
LNRGPPC≠ICT	4.554***	3.769	0.000	Yes
LNRENEW≠LNRGPPC	2.982	0.775	0.439	No
LNRGPPC≠LNRENEW	5.691***	5.912	0.000	Yes
LNGLO≠LNRGPPC	3.734**	2.210	0.027	Yes
LNRGPPC≠LNGLO	3.837**	2.405	0.016	Yes
LNRENEW≠ICT	3.717**	2.169	0.030	Yes
ICT≠LNRENEW	4.635***	3.909	0.000	Yes
LNGLO≠ICT	2.743	0.326	0.744	No
ICT≠LNGLO	4.768***	4.175	0.000	Yes
LNGLO≠LNRENEW	5.111***	4.812	0.000	Yes
LNRENEW≠LNGLO	3.799**	2.324	0.020	Yes

Note: ≠ indicates that one variable does not Granger cause the other. Granger causality relationship is found at 1% and 5%. significant levels

This finding is contrary to Chang et al. (2015), and Shakouri and Khoshnevis Yazdi (2017), who found a bidirectional relationship between RENEW and economic growth. Furthermore, a unidirectional casualty also holds from ICT to globalization at a 1% significant level.

We further found evidence of bidirectional causality. The result shows that ICT Granger causes economic growth, and vice versa at the 1% significant level; indicating that both ICT and economic growth could predict each other. The bidirectional causality between globalization and economic growth is significant at a 5% significant level; we also found that the causality running from globalization to RENEW was significant at 1% while RENEW to globalization at 10%. This indicates that globalization can predict economic growth more, compared to when economic growth predicts globalization.

5 Conclusion and policy recommendation

This study investigates whether renewable energy (RENEW) retard economic growth (RGPPC) in Sub-Saharan Africa (SSA) for the period 2005–2022 or not. The study accounted for the role of technology (ICT) and globalization (GLO) in stimulating economic growth. The Fisher-type Johansen cointegration, Pedroni, and Kao cointegration tests all established a long-run relationship between economic growth and the explanatory variables. The PMG ARDL was further deployed, and it was observed that both renewable energy and ICT exhibit a negative and significant impact on economic growth in the long run. The study further established a positive and significant impact of globalization and economic growth in the long run. This indicates the vital role of ICT and globalization in accelerating economic growth.

Based on the empirical findings, here are some workable policy suggestions for SSA: Given the negative impact of renewable energy and the positive impact of ICT on economic growth in the long run, SSA countries should prioritize investments in ICT infrastructure. Governments should focus on improving digital connectivity, expanding access to the internet, and fostering a conducive environment for technological innovation. While the overall impact of renewable energy on economic growth is negative in the short run, the study highlights that it has a positive impact on economic growth in specific SSA countries. Policymakers in these countries should encourage and incentivize investments in the renewable energy sector, especially in infrastructure development and improving electricity access. This could potentially stimulate economic growth, particularly in countries with low access to electricity and poor infrastructure.

Due to the negative impact of renewable energy on economic growth in countries with poor infrastructure and low access to electricity, SSA governments should prioritize infrastructure development. Improving transportation, energy, and communication infrastructure will create a more favorable environment for economic growth and enhance the positive effects of renewable energy. Since the study indicates that globalization has a positive and significant impact on economic growth in the long run, SSA countries should adopt policies that encourage international trade, foreign direct investment, and participation in the global economy. This could involve reducing trade barriers, improving business environments, and actively seeking foreign investment.

Considering the heterogeneity among SSA countries, policymakers should adopt a tailored approach based on the specific characteristics of each country. For instance, countries with poor infrastructure may need to focus on building a robust foundation, while those with higher renewable energy potential should invest strategically in this sector. Acknowledging the tendency of capital reversal in downturns, policymakers should focus on attracting long-term investments, particularly in the renewable energy sector. This may involve creating favorable conditions for foreign investors to engage in sustainable and long-term projects that align with the countries' economic development goals.

Countries with a positive impact of renewable energy on economic growth often have higher rates of accessibility to electricity. Policymakers should implement strategies to improve electricity access, such as investing in power infrastructure, promoting off-grid solutions, and enhancing energy efficiency. Countries with positive impacts of renewable energy on economic growth have a higher share of renewable energy in their total energy mix. Governments should promote policies that encourage a diversified and sustainable energy mix, incorporating renewable sources such as hydro and biomass.

Conclusively, recognizing the bidirectional causality between ICT and economic growth, policymakers should focus on strengthening the symbiotic relationship between information and communication technologies and economic development. This may involve supporting technology-driven entrepreneurship, digital education initiatives, and creating an innovation-friendly ecosystem. Despite its long-term positive impact, the study suggests that globalization does not matter in the short run. Policymakers should closely monitor globalization trends and be agile in responding to changing economic conditions. This could involve implementing policies that foster global economic integration, such as trade agreements and partnerships.

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