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Synthesizing the role of technological innovation on sustainable development and climate action: Does governance play a role in sub-Saharan Africa?

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ABSTRACT

The present study draws motivation from United Nation Sustainable Development Goals (UN-SDGs) and its impact by 2030. To this end, the current study explored the nexus between energy consumption (SDG-7), climate action (SDG-13), and economic growth (SDG-8) while controlling for role of government apparatus such as like voice of accountability, rule of law, control of corruption and technology innovation in a balanced panel of 46 Sub-Saharan African (SSA) economies from 1996 to 2020. For a robust study, the present study leverages on second-generation estimator such as cross-sectional SUR, two-stage least square (2SLS), 2SLS is referred to as the superior estimators to traditional pool OLS due to its capabilities of including endogenous regressors and efficiency. Empirical findings show that all the coefficients associated with mobile subscription (lnTI) are negative and statistically significant at 1% level of significance (P-value <0.01). This indicates that higher (lower) mobile cellular subscriptions results in the reduction (rise) of renewable energy consumption, implying that technological innovation in terms of the expansion of mobile cellular subscription hinders access to clean energy in SSA. Conclusively, the present study presents interesting outcomes concerning technology innovation, Governance, and SDGs goal 7 (clean energy) and 13 (climate action) in Sub-Saharan African blocs. Policy strategies are outlined in the concluding section.

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1. Introduction

Sustainable development necessitates concerted efforts to build a green ecological-friendly future (Arafath, 2022; Ofori and Appiah-Opoku, 2023). This underscores the justification for most governments' continual signing and ratification of environmental treaties. (Biermann et al., 2022; Goyeneche et al., 2022). As recently as November 2021, most governments met in Glasgow to reaffirm their commitment to net-zero emission (Arora and Mishra, 2021). In this new global awareness, it is reassuring that most governments progressively take responsibility for the problem and voluntarily establish national systems to achieve Sustainable Development Goals (SDGs). However, the parameters show Sub Sahara nations failing to meet the target. Even before the COVID-19 epidemic, OECD research showed that the road to the SDG objectives was still long (Dabbous and Tarhini, 2021; Ahmed et al., 2022; Shulla et al., 2021; Ferreira et al., 2022; Wang et al., 2022a,b). With fewer than ten years remaining to achieve the 2030 Agenda, it is critical to accelerate progress. The COVID-19 impasse stifled progress on several SDGs (Ofori et al., 2023a,b,c,d), making attainment even more crucial (Silveira et al., 2022; Zang et al., 2021; Syed and Bouri, 2021; Eslami et al., 2021). Environmental issues like climate change continue to pose significant systemic hazards to the health of both present and future generations (Fuller et al., 2022; Tilstra, 2022).

Adopting new technologies may potentially reduce ecological challenges (Burhan et al., 2017). According to research, innovation is the primary engine of sustainable growth. Although creating new sustainable technologies is crucial for addressing the social and environmental problems that society is currently facing, these technologies meet many obstacles (Ahl et al., 2022; Ofori et al., 2023a,b, c,d). Some obstacles include investment portfolios and uncertainty about its role in the sustainable debate. However, its contribution to access to clean energy, which tailors to reducing carbon emissions, cannot be overlooked, as reported by (Alola and Onifade, 2022; Obobisa et al., 2022; Onifade and Alola, 2022b). Recent proposals from academics and policymakers suggest that technological innovation leads the frontiers for sustainable development (Moshood et al., 2022; Polyviou and Zamani, 2022). This recommendation is based on two main ideas. (I) First, Technological innovation will shift the traditional model of production, which is a significant driver of pollution (Bradu et al., 2022; Płonka et al., 2022). (ii)Second, Technological innovation would be economically and ecologically beneficial since it would result in productivity increases and economic welfare advantages comparable to traditional models under the framework of the environmental Kuznets curve (Ge et al., 2022; Ofori et al., 2023a,b,c,d; Onifade and Alola, 2022a).

Within these parameters, it becomes essential to understand the path through which technology innovation help attain two important Sustainable development goal. This theorem is driven by four strands in academic and policy reforms: (I) The focus on technological innovation in developing countries; (ii) the impact of Governance on technology development and sustainable development. (iii) why focus on sustainable development 7 and 13; and (iv) gaps in earlier literature. These ideas are chronologically expanded on further down.

Firstly, Sub-Saharan Africa is an introductory case study for these two objectives due to its ecological issues and dismal track record for providing clean and affordable energy (Adewale Alola et al., 2021). The Region's growth throughout the SDG period has been much lower than the historical average and the SDG objective of 7% annually (Lin and Sai, 2022). This score may even get lower due to the increase in population and the distortion from covid 19—since the COVID-19 situation has severely obscured public discussion of the climate catastrophe (Phillips et al., 2020). Although several programs exist to increase access to electricity in Sub Sahara Africa, they still fall below the target metrics leading to climate change issues (Chirambo, 2018). Therefore, finding immediate responses to climate change and providing clean energy is imperative before the situation worsens. Unfortunately, Sub-Sahara Africa's economic development has been constrained by a lack of commitment to science and technology, both structurally (reluctant to accept new forms of production) and sectoral (knowledge barrier for most small-scale businesses to innovate). Consequently, the continent has continued to rely on the colonial conceptual framework of resource extraction, which is unsustainable and harms the environment. Primarily, technological innovation should be a driving force behind new production options, particularly those with a lower environmental effect, allowing SSA countries to continue producing without endangering the world. Additionally, due to their pursuit of economic development, these SSA economies continually rely on a traditional energy input source, making it challenging to protect their environment. The premise of these economies' development pursuit has been accompanied by a severe ecological deterioration, leading to increased worldwide CO_2 emissions. These prove the need to understand the phenomenal to help policymakers address this menace in Sub-Saharan Africa.

Second, Quality governance structures may help make technological innovation a reality. However, researchers have produced contrasting and ambiguous findings when governments in emerging countries embrace programs and regulations to lessen technological innovation's adverse environmental effects (Ofori et al., 2023a,b,c,d). Researchers have shown a substantial correlation between an increase in carbon emissions and technology transfer into developing market economies, validating the pollution-haven Hypothesis. However, we contend that the ability to plan and establish the necessity for accomplishing the SDGs is part of what is meant by "good governance.". Many issues, including employment, green industrialization, and climate actions, are connected with the objectives of good Governance. However, due to most SSA nations' poor growth framework, their governments have chosen a poor development strategy, which significantly harms the environment's ecological balance because it relies on overexploiting their natural resources and overbearing reliance on fossil fuels. Countries cannot fuel their growth without consistent energy, yet one out of every five SSA citizenry still lacks access to electricity. SDG -7 addresses this major problem by "ensuring access to cheap, dependable, sustainable, and modern energy for everyone (Amesho, 2019; Mustafa et al., 2022)". Countries can attain this goal by exploring renewable energy and deliberately structuring clean energy sources to support their strategic growth. Technology innovation is one of the drivers of this expansion. Renewable energy is another invention within the energy-climate deadlock that allows the same amount of energy to be provided without negatively impacting the environment. And such a policy regime is implemented or overseen by government entities.

Thirdly, this goal was inspired by the notion that both issues are interrelated and cannot be addressed individually and that resolving one impacts the execution of the other. Many current investigations have shown this link—for instance, several academics (Abbasi et al., 2022; Adebayo, 2022; Olabi and Abdelkareem, 2022; Pata, 2021), among others, offer various policy recommendations on the role clean energy plays in the fight over climate change. Also, the Sustainable Development Goals serve as a road map for achieving a better and more sustainable future for everybody. However, attaining 7 and 13 within the context of production and humanity activities will need conscious action and policy orientations, specifically for the need to achieve sustainable goals 7. Investing in clean and sustainable energy sources is vital in light of the recent surge in global energy demand, preventing energy crises, and the adverse effects of utilizing conventional energy sources. Since immemorial, society has been seeking and using natural resources such as natural gas, coal, and crude oil. These resources, collectively known as fossil fuels, are non-renewable and not sustainable. Although these kinds of energy have met human demands in many areas and have significantly contributed to the industrialization of nations that the world now enjoys, they have also harmed the environment.

On sustainable goal 13, the effects caused by the continuous use of the traditional energy source have led to the problem of climate change, which affects all facets of the economy. Global emissions are at record highs, with little sign of abating soon. One will be alarmed to want to understand why failure at achieving sustainable goals or harmonizing the climate change menace (Ofori and Appiah-Opoku, 2023). All nations on all continents are being impacted by climate change. It is harming people's lives and upsetting national economies. Sea levels are rising, weather patterns are shifting, and severe weather events are happening more often.

Fourthly and last will be several theoretical and methodological shortcomings at the root of these equivocal findings and policy implementation failures. Most works have been biased toward the contribution of Technological innovation. Since it is only considered one of the pillars of sustainability, such literature contends technological innovation only partly supports sustainable economic development. This opinion has been espoused in earlier literature by scholars like Donella et al. (1972) and (Freeman, 2013). Recently, researchers have questioned whether technological innovation is consistent with the reduction of carbon emissions or not rather than searching for the circumstances through which it might promote environmental sustainability. To determine these needs, we reviewed prior research on the relationships between effective Governance and CO_2 emissions, technological innovation and CO_2 emissions, governance quality, and technical innovation (Cheng et al., 2021; Omri and Hadj, 2020; Zhang et al., 2022). Based on these findings, we estimate that the improvement in governance quality is a necessary prerequisite for the positive relationship between technological advancements, a decrease in CO2 emissions (SSG 13), and the promotion of renewable energy (SDG 7). We circumvent certain methodological shortcomings in earlier research, summarised as follows.

(i) either using a few proponents of governance indicators or
(ii) not clearly distinguishing between economic, political, and institutional Governance. But our approach would use all these indicators to better understand the moderating function of Governance measurements.

The following are some ways that this investigation adds to the field of sustainability studies based on the four literary threads we've already covered.

The novelty of our study.

(1) First, although several studies already in existence have spoken about how important good Governance is to attain sustainable development, none have classified it or explained each theme area's role. For the 46 Sub-Saharan African nations included, good Governance is regarded as a determinate variable further separated into political, economic, and institutional components. The governance category study helps us determine which category is better at attaining this symmetry and streamlining policy directions. Furthering on broadening the policy relevance of this study, the panel data is decomposed into income levels based on World Bank groupings.
(2) Secondly, Our study underscores the essential interplay between SDG 7 and SDG 13, recognizing their intertwined nature. It emphasizes that actions directed towards one goal should be designed to yield positive outcomes for the other. By comprehending and harnessing this interconnectedness, policymakers, researchers, and stakeholders can develop targeted strategies and interventions that effectively address both SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action)
(3) The empirical findings of these tests hold substantial economic implications and offer practical recommendations for environmentalists, policymakers, governing bodies, citizens, and researchers, particularly in Sub-Saharan African (SSA) countries that encounter challenges related to Sustainable Development Goal (SDG) 7 and SDG 13. Given the minimal technology penetration in these regions, it is crucial to encourage increased investment in the technological sector, as it can play a pivotal role in supporting the achievement of SDG Goals 7 and 13. This would not only address the existing issues but also foster a conducive environment for further technological advancements and advancements towards sustainable development.

The remainder is structured as follows. Section 2 discusses the theoretical basis and development of ideas relating to sustainability. Section 3 discusses the data and approach. Section 4 summarises and examines the empirical findings, followed by policy suggestions in Section 5.

2. The theoretical underpinning of the study

The Novel work of Grossman and Helpman (1993) provides the theoretical framework for our work, .where he opines innovation as an outlier for growth induce economy. However, scholars have relayed the problems associated with development known as the environment Kuznets curve (Anwar et al., 2022; Patel et al., 1995; Wang et al., 2022a,b). This makes it incumbent to ensure green innovation which is friendly to the environment.

Environmental sustainability is a fundamental policy priority in the post-2015 development agenda and now post COP26 meeting in Glasgow. It is especially acute in the SSA sub-region for at least four reasons. **(I)** It is reasonable to conclude that the more than two decades of economic revival in SSA have been associated with higher CO_2 emissions. According to Asongu and Nwachukwu (2017) and (Jian et al., 2022), the sub-region is home to seven of the world's ten fastest-developing economies, and there is an inclination toward the theory of the environmental Kuznets curve. **(ii)** According to Hervieux and McKee (2022) and (Akinyemi et al., 2021), one of the most challenging policy symptoms there is an energy problem in the post-2015 age of sustainable development and post covid era. Sub-Saharan Africa was anticipated to experience the pandemic's worst effects when it began to spread due to poor energy access, which affects healthcare delivery. According to (Chakravorty et al., 2022), this situation is evident in SSA since barely 5% of the sub-population region has access to electricity. The story goes on to say that the energy usage in SSA, which is around 17% of the world average, is insufficient for any transformational agenda but poses a threat to the environment because of this high fossil composition. **(iii)** Further motivation spun from the social-economic ramifications of poor handily of energy-related crises as seen in the novel work (Soumonni and Soumonni, 2011). Nigeria and Ghana are prime examples of mismanagement, with persistent energy shortages. Government subsidies on fuel imports compensate for the shortfall—however, it compounds the debts of such economies and sadly still doesn't address environmental sustainability. Alternatively, a prudent method would have been to increase public investment in renewable energy sources to lower greenhouse gas emissions. **(iv)** Post-COP26: reports still indicate Climate change is a crucial policy issue. Syndromes of overdependence on fossils and discard for policy direction in SDGs 7 and 13 (see (Awan, 2022; Sachs et al., 2019; Santos et al., 2022). Furthermore, the impacts of global warming will disproportionately affect developing nations, especially SSA (Fotio et al., 2022; Sachs et al., 2019).

3. Empirical literature

3.1. Technological innovation on sustainable development goal 7 (affordable and clean energy)

Various studies have explored the relationship between technological innovation and affordable and clean energy in the empirical literature. For instance, starting with a recent paper (Ullah et al., 2023; Tavanti, 2023) contribute immensely towards the prospects of renewable energy One key attribute is the role of technology in expanding access to energy. They highlight how innovative solutions, such as off-grid renewable energy systems and decentralized energy generation, can provide electricity to remote and underserved communities.

Also Altıntaş and Kassouri (2020) examine how changes in the budgetary provision for research and development in energy technology affect carbon footprints and renewable energy in European countries using a linear and non-linear ARDL approaches. The result for the linear model shows that technological innovation measured budgetary provision for R&D in energy contributes positively to renewable and clean energy. However, the non-linear outcome shows both positive and negative changes in budgetary provision enhances environmental quality; this implies an expansionary budgetary of technological innovation has more impact on environmental quality than a contractionary budget. Usman and Radulescu (2022) investigate whether technological matters for renewable energy in reducing carbon footprint using second-generation panel estimation techniques. The outcome suggests that technological innovation lessens environmental sustainability. Similarly, Liu and Liang (2013) highlighted the Chinese experience of technological innovation in clean energy. Technological innovation is mainly driven through increase expenditure in R&D which promotes clean energy by cutting the use of fossil fuels and fostering the use of non-fossil and renewable energy. Also, massive investment in strategic industries will enhance energy conservation, healthy environment, clean energy for cars, and biotechnology. In the BRICS countries, as a result of enormous industrialization with high energy demand. Sharma et al. (2021) discovered that technological innovation has escalated the use of clean energy. The result suggests that the growing demand for energy has led to the rise in the use of clean energy, thereby enhancing environmental quality. For the ECOWAS countries, Mohsin et al. (2022) examined the relationship between technological progress, renewable energy, and green economic growth. The result shows advancement in new technology has led to low carbon emission and better production techniques.

Shan et al. (2021) focused on the role of green technological innovation in providing efficient and clean energy for sustainable development in Turkey. Given the composition of green technology as a broad term that consists of regulation pollution, ecological control, recycling, and purification. It is a fundamental determinant of environmental quality. Using the bootstrap ARDL estimation, data for carbon emission was examined against technological innovation, energy consumption, and renewable energy. The finding shows that in the long-run green technology innovation and renewable energy support the reduction of carbon emission.

3.2. Technological innovation on sustainable development goal 13 (climate action)

Numerous studies have shown that technological advancement can mitigate climate change. Commencing with a recent work of (Ofori and Appiah-Opoku, 2023; Javed et al., 2023) both agree technology is a pillar in achieving the SDG Goal specifically for SDG 13 Technology, in its various forms, offers innovative solutions and tools that can facilitate the transition to a low-carbon and climate-resilient future either as ICT, Internet or green innovation .Using CO_2 emission as a measure of climate change Lin and Zhu (2019) study the association between CO_2 emission and renewable energy technological innovation in China. The outcome from the linear regression indicates that renewable energy technology significantly lessens CO_2 emission. Sun et al. (2021) study the spillover effect of new innovative technology in reducing climate change from developed to developing countries. Taking geographical distance into consideration and using data for 24 OECD countries with the aim of determining how local and foreign innovations impress on a country's energy performance. The study concludes that technological innovation through patents in US and Germany spilled over to the Netherlands, thereby enhancing efficient energy and promoting a conducive climate. Considering the effect of climate change and measures developed to assuage such effect (Su et al., 2020). contribute to the literature on climate change by incorporating the effect of technological innovations and international trade on CO_2 emission in the US. Their study employs the ARDL approach. The result shows that technological innovation has a controlling effect on the growth of carbon emissions. This signifies that new technologies emit less harmful substances which contribute to environmental quality.

Adenle et al. (2015) analyze the effect of research and development in promoting new and existing technology to mitigate climate change. Their investigation finds that in developing countries, investment in R&D relevant to new technology which will lessen climate change has been minimal. The limitations to promoting technological innovations include a weak credit system, poor infrastructure, weak research capacity, and absence of technology transfer. Also, consistent with other findings, Chien et al. (2021) used the quantile ARDL estimation to study the impact of renewable energy, globalization and technological innovation on environmental degradation in Pakistan. The finding suggests that globalization support the growth of CO_2 emission. However technological innovation and renewable energy mitigate environmental degradation. Wang et al. (2019) showed that the experience from China towards technological innovation to lessen the effect of climate change are mainly related to solar energy, electric vehicles, lighting, waste disposal through recycling and water management.

Mensah et al. (2019) investigate the role of technological innovation on the growth of green energy in the OECD countries. By employing the STIRPAT and IPAT models the outcome revealed that energy utilization from the transport sector for the countries in America, Oceania and Asia hurt the growth of green energy and by extension harmful to the environment. Similarly, energy consumption by industries in the overall OECD was discovered to hinder green energy growth. Substantiating the role of transport and industries in increasing environmental pollution. In contrast, technological innovation contributed immensely to the rise of green energy growth, with Oceania having a greater impact. Cafaro (2014) opines that technological innovation is a necessary condition but not sufficient to mitigate climate change because of human activities that result in pollution, consumption, and economic growth. The study suggests controlling the population by granting reproductive freedom to women; regulating consumption through carbon tax, flying less and minimizing consumption of luxury goods; and reducing the economy's size through fiscal and monetary policies.

3.3. Literature gap

A major gap is the failure of literature to synergise the complementary SDG goal, that is 7 and 13. Aggregating all the diverse empirical studies as it relates to technological innovation and SDG 7 (affordable and clean energy) and technological innovation and SDG 13 (mitigating climate change) reveals that most new technologies are valid towards promoting clean energy and assuaging the effect of climate change except in some developing countries where the level of infrastructural development, low budgetary provision for research and development, weak technological transfer among others have hindered technological innovation towards making any significant impact on clean energy and climate change. However, the Sub-Saharan African countries are developing countries, and most of these factors prevent their success in a sustainable environment. Broadly speaking, these are governance issues that affect policies and implementation regarding new technology and environmental quality. The interaction of technological innovation with Governance in promoting a sustainable environment has been missing in the literature. This study contributes by filling this gap.

4. Methodology

A systemic transformation base on technological innovation to enhance ecological protection under the supervision of the Government is salient in this 21st century in Sub Sahara Africa. Compared to other blocks such as the European Union, the pace of sustainable energy development in Sub Sahara, Africa is sluggish. Thus, SSA may benefit from the EU's policies to boost RE and solve climate issues. Comprehensive and effective RE laws and regulations are required to maximize the potential of these renewable resources and eventually navigate towards SDGs 7 and 13, which aim to safeguard the environment. The justification for the ambit of SSA was stated in the introduction and built on in our literature. Further down, we would try to use econometric models to assess the situation to inform policy reforms for the Government.

4.1. Data

Our research is based on a balanced panel of 46 Sub-Saharan African nations from 1996 to 2020. The historical period was chosen due to the availability of governance indicators. The following are the primary factors we utilized to highlight the effect of technological innovation and the moderating influence of Governance in reaching SDGs 7 and 13.

4.1.1. .Sustainable development goal 7

This goal seeks to provide affordable and clean energy to society, as detailed below: This variable was proxies as renewable energy.

4.1.2. Sustainable development goal 13

Climate change is driven by rising greenhouse gas emissions. Climate change is a clear and genuine danger to our whole civilization. The consequences are already apparent and will be disastrous unless we act quickly. We can make the necessary adjustments to safeguard the earth via education, innovation, and adherence to our climate obligations. in our work, we proxied SDG 13 with carbon emission.

4.1.3. Technological innovation

Most works proxied technological innovation with patents (Rasulov, 2022; Wang and Zheng, 2022) and Research and development (Boeing et al., 2022; Ma et al., 2022). However, due to inconsistent Data in the SSA region, our work will be proxied on access to technological innovation using mobile subscription (Su et al., 2018) and the Internet coverage (Rout et al., 2022), an improvement of the model of Adewale Alola et al. (2021) and (Haldar and Sethi, 2022). In the first model, we consider renewable energy as technology innovation within the energy mix impasse.

4.1.4. Good governance

A seamless and enabling environment created by the government provides a cushion for implementing any plan. Thus, attaining the goal of the SDG will have to be championed by Government**.** We look at six governance metrics divided into three categories: economic Governance (government effectiveness; regulatory quality), political Governance (political stability; Voice and Accountability), and institutional Governance (control of corruption; the rule of law). These six factors are also employed in contemporary governance research (Chambers and Munemo, 2019; Omri, 2020).

4.1.5. Economic growth

Most government activities are propelled by investment or capital; hence the Gross domestic product will be used as a control variable within the study.

4.2. Estimation approach

Building on the framework of prior literature Adenle (2020) ; Usman and Balsalobre-Lorente, 2022, and Gyamfi et al. (2022). We employ an econometric model to ascertain the role of technology innovation in attaining sustainable goals 7 and 13, respectively, under an enabling environment stimulated by good Governance. Our work covers 45 sub-Sahara African countries with 24 middle-income and 21 lower-income states spanning 24 years from 1996 to 2020 (See appendix). A second generational method is also adopted to provide reliable results best suited for policy recommendations.

4.2.1. Model 1 SDG GOAL 7

To accomplish this, technologies that provide clean and affordable energy services must be developed and deployed quickly. However, policymakers must be informed by econometric metrics indicating this Hypothesis Thus SDG7 is to be achieved by using key innovations. This model is routed to understand these innovations' key requirements, their expanded deployment difficulties, and solutions to these difficulties. Additionally, Sub-Saharan Africa faces many challenges and obstacles in modernising traditional energy sources, and this model aims to determine whether technological advancements can support SDG goal 7 within this Region, as seen in

$$\mathrm{REN} = \mathrm{f}(TI, Ti1, CO_2, GE, RG, PS, VOA, CC, RUL, Y) \tag{1}$$

and expanded in *equation 2*

$$REN = f(TI, Ti1, CO_2, GE, RG, PS, VOA, CC, RUL, Y) \tag{2}$$

Where all the variables are expressed in Table 1. The equation is then expressed as a logarithm

$$\ln Ren_{it} = \beta_0 + \beta_1 \ln TI_{it} + \beta_2 \ln TI1_{it} + \beta_3 \ln C02_{it} + \beta_4 \ln GE_{it} + \beta_5 \ln RG_{it} + \beta_6 \ln PS_{it} + \beta_7 \ln VOA_{it} + \beta_8 \ln CC_{it} + \beta_9 \ln RUL_{it} + \beta_{10} \ln Y_{it} + \alpha_{it} \tag{3}$$

Where TI. Ti1, CO_2, GE.RG, PS, VOA, CC, RUL and Y the above-mentioned coefficients Moreover, $\beta_0 \ldots \beta_{10}$ denotes the regressor coefficients, while i and t represent countries from the pane; and timeframe, respectively. This equation justifies the path route for model one.

Table 1
Data description and source.

Variable indicators	Series Name	ID	SOURCE
Sustainable Development Goal 7	Renewable energy consumption (% of total final energy consumption)	REN	WDI
Sustainable Development Goal 13	CO2 emissions (kg per 2015 US$ of GDP)	CO2	WDI
Technology Innovation	Mobile cellular subscriptions	T1	WDI
Technology Innovation	Individuals using the Internet (% of population)	T11	WDI
Economic Governance	Government Effectiveness: Estimate	GE	WDI
Economic Governance	Regulatory Quality: Estimate	RG	WDI
Political Governance	Political Stability and Absence of Violence/Terrorism: Estimate	PS	WDI
Political Governance	Voice and Accountability: Estimate	VOA	WDI
Institutional Governance	Control of Corruption: Estimate	CC	WDI
Institutional Governance	Rule of Law: Estimate	RUL	WDI

4.2.2. Model 2 SDG GOAL 13

Utilizing technological advancements can help lessen the threat of climate change. The use of environmentally friendly fuels is encouraged by innovations like clean energy and smart cities encourage the use of environmentally friendly fuels, which lower carbon emissions. Momentous solutions that go beyond disruptive innovations are necessary to achieve exponential goals. However, the contribution of innovation cannot be discounted. Hence, this second model would access the benefit component of innovation to achieving SDG 13 in Sub Sahara Africa as seen in the

$$CO_2 = f(TI, Ti1, REN, GE, RG, PS, VOA, CC, RUL, Y) \quad 4$$

and expanded in equation 5

$$CO2 = f(TI, Ti1, REN, GE, RG, PS, VOA, CC, RUL, Y) \quad 5$$

$$\ln C02_{it} = \beta_0 + \beta_1 \ln TI_{it} + \beta_2 \ln TI1_{it} + \beta_3 \ln Ren_{it} + \beta_4 \ln GE_{it} + \beta_5 \ln RG_{it} + \beta_6 \ln PS_{it} + \beta_7 \ln VOA_{it} + \beta_8 \ln CC_{it} + \beta_9 \ln RUL_{it} + \beta_{10} \ln Y_{it} + \alpha_{it} \quad 6$$

4.3. Econometric strategy

For econometric analysis, preliminary tests are often required to establish data validity and consistency. As a result, before model evaluation, we ran certain tests, including (1) Kaiser–Meyer–Olkin measure of sampling adequacy and scree plot, (2) the cross-sectional dependency and homogeneity test, (3) The Panel unit root, and the cointegration test, (4) the correlation matrix. To determine the stationarity, we used Pesaran et al. (2013) panel unit root tests, namely the cross-sectionally augmented panel unit root test (CIPS) and the cross-sectionally augmented Dickey-Fuller test (CDF) (CADF). The reason is that they produce consistent and unbiased findings.

Subsequently, we used a CSD test to determine unobserved factors prevalent in the panel to inform the method employed to test the Hypothesis. Following the cross-sectional dependency test, we used the Persyn and Westerlund (2008) tests to examine the long-run connection between the variables, another method that further confirms a suitable analysis method. High correlation coefficients between independent factors and dependent variables may indicate multicollinearity difficulties in the model. As a result, we constructed a correlation matrix to check for such deficiency to guarantee that there was none. We used a sample adequacy test to ensure that we could depend on the sample chosen for the research. In that context, we ran the KMO and Bartletts' sphericity tests which are available in the appendix section.

Following thorough, positive preliminary testing, we carried out the long-run parameter estimates. For a robust study, the assessments are performed using a second-generation estimator. Cross-sectional SUR, two-stage least square (2SLS), 2SLS is referred to as the superior estimators to pool OLS due to its capabilities of including endogenous regressors and efficiency. These address the problems of simultaneity, cross-sectional endogeneity, and panel heterogeneity.

4.4. Correlation analysis and the test of multicollinearity

The correlation analysis is conducted to examine the presence of multicollinearity in the data. The result is presented in Table 3. It

Table 2
Descriptive Statistics for full sample middle income and lower income.

Variables	lnREN	$lnCO_2$	nTI	nTI1	nGE	nRG	lnPS	lnVOA	lnCC	lnRUL	lnY
Full Variables											
Obs	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125
Mean	5.103	1.346	4.58	13.071	0.17	0.269	0.242	0.23	0.389	0.156	9.899
Std. Dev.	0.171	0.064	0.125	3.78	0.516	0.523	1.044	0.642	0.414	0.574	0.12
Min	4.612	1.265	4.488	1.099	−1.801	−3.528	−7.002	−3.752	−0.957	−2.631	9.811
Max	5.29	1.803	5.124	19.114	1.134	1.295	1.248	1.101	1.469	1.239	10.463
Skew.	−1.268	2.383	1.76	−1.419	−0.689	−2.253	−2.606	−1.647	−0.201	−1.154	2.341
Middle Income											
Obs	600	600	600	600	600	600	600	600	600	600	595
Mean	5.008	1.373	4.617	13.181	0.326	0.35	0.577	0.348	0.487	0.302	9.958
Std_Dev	0.181	0.072	0.149	3.658	0.494	0.582	0.606	0.699	0.446	0.527	0.139
Min	4.612	1.269	4.488	1.099	−1.293	−3.528	−2.663	−3.752	−0.957	−1.913	9.827
Max	5.269	1.803	5.124	19.114	1.134	1.295	1.248	1.101	1.469	1.239	10.463
Skew	−0.6	2.019	1.232	−1.362	−0.788	−2.612	−2.259	−2.165	−0.448	−0.947	1.614
Lower income											
Obs	525	525	525	525	525	525	525	525	525	525	525
Mean	5.212	1.315	4.538	12.946	−0.008	0.176	−0.141	0.096	0.276	−0.01	9.832
Std_Dev	0.057	0.03	0.07	3.915	0.482	0.43	1.282	0.539	0.341	0.58	0.02
Min	4.997	1.265	4.489	1.099	−1.801	−2.623	−7.002	−1.957	−0.74	−2.631	9.811
Max	5.288	1.425	4.757	17.529	0.838	0.832	1.018	0.81	1.04	0.745	9.913
Skew	−1.406	1.637	1.731	−1.459	−0.888	−1.867	−2.047	−1.068	−0.321	−1.428	2.664

Table 3
Pairwise correlation.

	lnREN	lnCo2	lnTI	lnTI1	lnGE	lnRG	lnPS	lnVOA	lnCC	lnRUL	lnY
lnREN	1										
lnCo2	−0.561***	1									
lnTI	−0.512***	0.229***	1								
lnTI1	−0.0405	0.0630*	0.386***	1							
lnGE	−0.433***	0.237***	0.289***	0.0606*	1						
lnRG	−0.326***	0.0722*	0.211***	0.0869**	0.754***	1					
lnPS	−0.393***	0.267***	0.147***	−0.129***	0.501***	0.449***	1				
lnVOA	−0.228***	0.107***	0.215***	0.0685*	0.621***	0.621***	0.446***	1			
lnCC	−0.451***	0.207***	0.312***	−0.0178	0.797***	0.708***	0.482***	0.712***	1		
lnRUL	−0.455***	0.190***	0.305***	0.0781**	0.820***	0.823***	0.581***	0.684***	0.820***	1	
lnY	−0.762***	0.391***	0.493***	0.0286	0.278***	0.195***	0.277***	−0.0241	0.216***	0.283***	1

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
The correlation analysis is conducted to examine the nature and strength of the relationship between the variable.

shows a mixture of positive and negative correlations among the variables. Furthermore, the correlation coefficients indicate weak correlations (coefficients less than 0.6) among most of the variables. However, there are few exceptions in the case of the governance indicators, which exhibit strong correlations; this connotes the likelihood of the problem of multicollinearity in the data. Therefore, the governance indicators were introduced to the models both concurrently and individually to surmount the possible multicollinearity in the data. Prior preliminary analysis of the basic summary statistics is presented in Table 2 for a full sample. The pairwise correlation analysis results are presented in Table 3.

5. Empirical results

5.1. Results of cross dependency and panel unit root tests

Cross-sectional dependence (CD) occurs in a situation where strong cross-sectional correlations are caused by a common factor which is unobservable (Pesaran, 2007). It an important issue for the choice of appropriate techniques of panel data analysis because when the strong cross-sectional correlations are ignored, the estimates will be invalid and unreliable, leading wrong statistical decisions, and misleading conclusion about the issues under investigation. In short, the estimates will be unreliable when CD is not accounted for in the panel unit root tests (PURT), cointegration tests, and the regression analysis. The data we used in the current study is prone to the problem of CD because of the intensity of globalization, economic integration, and neighborhood effect. Thus, it is imperative to test for the presence of CD in the data.

In this study, we used Breusch-Pagan LM test (Breusch and Pagan, 1980), Pesaran scaled LM test (Pesaran, 2004), and Bias-corrected scaled LM (Baltagi et al., 2012) to examine the presence of CD in all the variables. We present the result in Table 4 T he null hypothesis of the tests is that the variable is cross-sectionally independent – no CD and the alternative hypothesis is that the variable is cross-sectionally dependent – CD is present. The results of all the tests show strong evidence of the presence of CD for all the variables. This is revealed by the test statistics, which are statistically significant for all the variables across the different tests. Hence, the results of the CD tests robustly show the presence of cross-sectional correlations among the countries for all the variables. Intuitively, the presence of the CD suggests that the effect of a shock on a variable in any of the countries will spillover to other countries in the panel. This reflects the reality because the increasing wave of political, economic, and cultural globalization could influence the fluctuation and nexus of the variables considered. The countries considered in this study share common region and economic blocs and have similar institutions and structures that may cause strong cross-sectional correlations among them. Therefore, we employ the second-generation panel data techniques, which account for CD in the all the analysis in this study.

Furthermore, we used the CADF and CIPS tests to examine the stationarity of the variables. These techniques account for the CD (Pesaran et al., 2008), and the null hypothesis of both test is that the series are stationary in all the cross-sections while the alternative hypothesis is that the series has unit root in at least one of the cross-sections. The rejection of the null hypothesis suggests non-stationarity of the variables. The results of both tests at levels and first difference and the result is also reported in Table 4. The estimates of both CADF and CIPS show that, at 5% level of significance, only lnTI1 is stationary at level while all other variables are stationary at first difference. Therefore, the results of the second-generation panel unit root tests revealed mixed order of integration with most of the variables being stationary at first difference. This suggests that a shock (positive or negative) will have permanent effect on most of the variables, (stationary at first difference) while shock (positive or negative) will have transitory effect on the percentage of population using internet (TI1).

5.2. Result of slope homogeneity test

We also conducted the (Pesaran and Yamagata, 2008) slope homogeneity test to establish the whether the slope coefficients are homogeneous or heterogeneous. The result of the test is displayed in Table 5. The test result shows that the estimated statistics (Delta = 20.665; P-value = 0.00, and Adj = 28.765; P-value = 0.00) are highly significant at 1% level of significance. This connotes the rejection of the null hypothesis that the slope coefficients are homogeneous. So, the slope coefficients are heterogeneous, and the econometrics procedure and techniques used in this study account for slope heterogeneity.

Table 4
Cross dependency and panel unit root test.

Variables	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	CIPS 1 (0)	CIPS 1 (1)	CADF 1 (0)	CADF 1 (1)
lnREN	9247.313***	185.5693***	184.6318***	−1.745	−4.134***	−0.681	−8.747***
lnCo2	5579.153***	103.1335***	102.196***	−1.766	−4.596***	0.262	−11.911***
lnTI	21,618.38***	463.5883***	462.6508***	−0.920	−3.105***	−0.620	−7.266***
lnTI1	22,379.36***	480.6901***	479.7526***	−3.348***	−3.966***	−12.505***	−14.493***
lnGE	4210.191***	72.36842***	71.43092***	−1.847	−4.822***	1.747	−11.142***
lnRG	4664.588***	82.58022***	81.64272***	−2.021	−5.171***	−0.643	−13.517***
lnPS	4090.027***	69.66792***	68.73042***	−2.057*	−4.998***	−1.771*	−12.687***
lnVOA	4461.855***	78.02413***	77.08663***	−1.939	−4.376***	−2.564*	−9.044***
lnCC	4156.302***	71.15736***	70.21986***	−1.662	−4.558***	1.067	−9.985***
lnRUL	4865.098***	87.08635***	86.14885***	−1.949	−4.762***	0.332	−9.243***
lnY	11,659.75***	239.7847***	238.8472***	−1.467	−3.870 ***	0.564	−6.773***

Table 5
Westerlund homogeneity test results.

	Value	P-value
Delta	20.665	0.00***
adj.	28.765	0.00***

5.3. Result of westerlund ECM panel cointegration test

Given the results of the CD tests and the unit root tests, we applied the (Westerlund, 2007) panel cointegration test to examine the existence of long-run relationship among the variables. The test accounts for CD and the null hypothesis of the test are 'no cointegration' while the alternative hypothesis is 'there is cointegration'. The results of the test with trend and without trend are contained in Table 6. The estimates show that the Gt, Pt, and Pa statistics are statistically significant at 1% level of significance. This indicates the rejection of the null hypothesis – the presence of cointegration among the variables. Therefore, the result of the cointegration test revealed a long-rung equilibrium relationship among the variables considered in the current study.

5.4. Regression results

To evaluate the nexus between technology, governance, and SDGs goal 7 – clean energy, and SDGs goal 13 – climate action, we estimated all the models in this study using Two-Stage Least Square (2SLS) estimator (Bollen, 1996). For each of the models we presented the estimates of the indicators of technological innovation, and the governance indicators with renewable energy consumption and carbon dioxide, which represent clean energy and climate change as dependent variables respectively. For the purpose of capturing heterogeneity and avoiding multicollinearity, in each model, the indicators of Governance were categorized into three –political Governance (PG), and institutional Governance (IG). The economic Governance (EG) represented by government effectiveness (GE) and, regulatory quality (RG); political Governance in indicated by political stability (PS), and voice and accountability (VOA), while institutional Governance is denoted by control of corruption (CC), and rule of law (RUL). The estimates are presented in different columns for each category of governance indicator. First, each table contains the column where all the indicators of Governance are included concurrently, and in categories. We also estimated the models in which the indicators of Governance were included separately. We also estimated the models for full sample of all the 46 sub-Sahara Africa, and subsamples of middle-income and lower-income countries in sub-Sahara Africa. The results are interpreted as follows.

5.5. Impact of technological innovation, and governance, on renewable energy consumption in Sub-Sahara Africa (full sample)

Table 7 contains the estimates of the 2SLS regression concerning the nexus between impact of technological innovation, and Governance, on renewable energy consumption for the 46 Sub-Sahara African (SSA) countries sampled in this study. The estimates show that all the coefficients associated with mobile subscription (lnTI) are negative and statistically significant at 1% level of significance (P-value <0.01). This indicates that higher (lower) mobile cellular subscriptions results in the reduction (rise) of renewable energy consumption, implying that technological innovation in terms of the expansion of mobile cellular subscription hinder access to clean energy in SSA. Conversely, the elasticities estimate of the percentage of population using internet (lnTI1) in all the models are positive and statistically significant. This suggests a positive nexus between internet penetration and renewable energy consumption in the SSA subregion as indicated by prior work of (Ibrahim et al., 2022). Hence, the results show that technology innovation can either promote or hinders access to clean energy in SSA. However, the magnitude of the impact of Mobile cellular subscriptions (estimates ranging from -0.2562 to -0.1624) is greater than the impact of internet penetration (estimates ranging from 0.0036 to 0.0016) on the renewable energy consumption, thus the negative impact of technology innovation outweighs its positive impact on access to clean energy in SSA.

Moreover, the result revealed that the parameter estimates of all the governance indicators in all the models are negative and highly statistically significant at 1% level of significance. This shows that green Governance in the SSA could result in the reduction of renewable energy consumption in the region. Finally, the parameter estimates of carbon emission (lnCO2) and GDP per capita (lnY), used as control variables, are negative and significant at 1% in all the estimated models. This shows that an increase (decrease) in carbon emission and income per capita will lead to decline (increase) in the consumption of renewable energy – clean fuels. As income increases the demand for goods and services will rise leading to increase in production, which spurs the consumption of fossil-based

Table 6
Westerlund ECM panel cointegration tests.

	Without trend				With trend			
Statistic	Value	Z-value	P-value	Robust P-value	Value	Z-value	P-value	Robust P-value
Gt	−2.55	−2.252	0.012	0.000***	−2.547	−0.717	0.237	0.000***
Ga	−7.675	3.139	0.999	0.450	−6.735	5.447	1.000	0.900
Pt	−29.78	−15.988	0.00	0.000***	−32.924	−17.089	0.000	0.000***
Pa	−12.812	−5.475	0.002	0.000***	−12.512	−2.837	0.002	0.000***

Table 7
2SLS Results on the nexus between technology, governance, Renewable (clean) energy (sustainable Development goal 7).

	Dependent variable: Renewable energy consumption									
	Governance	Economic Governance			Political Governance			Institutional Governance		
	Gov	EG	GE	RG	PG	PS	VOA	IG	CC	RUL
lnTI	−0.1624***	−0.2267***	−0.2231***	−0.2422***	−0.1972***	−0.2562***	−0.1924***	−0.1677***	−0.1628***	−0.2089***
	(-5.75)	(-8.06)	(-7.89)	(-8.64)	(-6.91)	(-9.00)	(-6.73)	(-6.01)	(-5.84)	(-7.54)
lnTI1	0.0016*	0.0034***	0.0031***	0.0036***	0.0024***	0.0022**	0.0029***	0.0020**	0.0016**	0.0032***
	(-1.85)	(-4.04)	(-3.71)	(-4.35)	(-2.87)	(-2.52)	(-3.47)	(-2.36)	(-1.97)	(-3.92)
lnCO2	−0.7311***	−0.7890***	−0.7557***	−0.8308***	−0.7378***	−0.7518***	−0.7613***	−0.7407***	−0.7357***	−0.7762***
	(-15.52)	(-16.46)	(-15.90)	(-17.67)	(-15.58)	(-15.42)	(-16.18)	(-16.24)	(-16.11)	(-16.82)
lnGE	0.0194*	−0.0339***	−0.0597***							
	(-1.91)	(-3.93)	(-10.35)							
lnRG	0.0023	−0.0330***		−0.0572***						
	(-0.24)	(-4.00)		(-10.38)						
lnPS	−0.0054				−0.0107***	−0.0233***				
	(-1.61)				(-3.33)	(-8.00)				
lnVOA	−0.0066				−0.0418***		−0.0497***			
	(-1.01)				(-8.32)		(-11.17)			
lnCC	−0.0833***							−0.0772***	−0.0994***	
	(-6.24)							(-6.60)	(-14.36)	
lnRUL	−0.0215*							−0.0201**		−0.0659***
	(-1.83)							(-2.34)		(-12.75)
lnY	−0.7774***	−0.7434***	−0.7490***	−0.7469***	−0.8158***	−0.7468***	−0.8403***	−0.7664***	−0.7796***	−0.7362***
	(-25.99)	(-26.11)	(-26.16)	(-26.08)	(-27.56)	(-25.51)	(-29.17)	(-27.46)	(-28.46)	(-26.24)
Constant	14.5410***	14.5337***	14.5262***	14.6923***	15.0557***	14.6584***	15.3010***	14.4634***	14.5748***	14.3617***
	(-59.01)	(-61.66)	(-61.22)	(-62.86)	(-62.92)	(-60.69)	(-66.91)	(-63.15)	(-64.93)	(-61.68)
No. Of Obs	1116	1116	1116	1116	1116	1116	1116	1116	1116	1116
R-Squared	0.739	0.719	0.715	0.715	0.721	0.704	0.719	0.737	0.736	0.727
F Statistic	313.169	471.966	555.637	556.016	478.61	528.062	566.971	518.742	618.899	591.146

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, (.) is t-statistics.

Table 8
2SLS Results using sustainable Development goal 13 (Carbon emission).

Independent variables	Dependent variable: Carbon emission									
	Governance	Economic Governance		Political Governance			Institutional Governance			
	Gov	EG	GE	RG	PG	PS	VOA	IG	CC	RUL
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
lnTI	−0.0561***	−0.0602***	−0.0561***	−0.0529***	−0.0489***	−0.0566***	−0.0529***	−0.0533***	−0.0501***	−0.0514***
	(-3.40)	(-3.73)	(-3.40)	(-3.26)	(-2.93)	(-3.46)	(-3.17)	(-3.19)	(-3.00)	(-3.13)
lnTI1	0.0019***	0.0017***	0.0014***	0.0015***	0.0016***	0.0016***	0.0014***	0.0015***	0.0013***	0.0014***
	(-3.99)	(-3.53)	(-2.96)	(-3.25)	(-3.380	(-3.26)	(-2.93)	(-3.09)	(-2.7)	(-3.03)
lnREN	−0.2447***	−0.2489***	−0.2456***	−0.2641***	−0.2433***	−0.2346***	−0.2507***	−0.2593***	−0.2576***	−0.2615***
	(-15.52)	(-16.46)	(-15.90)	(-17.67)	(-15.58)	(-15.42)	(-16.18)	(-16.24)	(-16.11)	(-16.82)
lnGE	0.0253***	0.0237***	−0.0007							
	−4.33	−4.91	(-0.20)							
lnRG	−0.0287***	−0.0322***		−0.0162***						
	(-5.21)	(-7.06)		(-5.03)						
lnPS	0.0076***				0.0057***	0.0038**				
	(-3.97)				(-3.080	(-2.27)				
lnVOA	0.0029				−0.0071**		−0.0032			
	(-0.75)				(-2.39)		(-1.18)			
lnCC	−0.0038							0.0045	−0.0088**	
	(-0.48)							(-0.63)	(-1.99)	
lnRUL	−0.0131*							−0.0123**		−0.0098***
	(-1.93)							(-2.42)		(-3.07)
lnY	−0.0355	−0.0349*	−0.0312	−0.0405**	−0.0480**	−0.029	−0.0397*	−0.0356*	−0.0416*	−0.0390*
	(-1.62)	(-1.72)	(-1.51)	(-1.98)	(-2.18)	(-1.41)	(-1.81)	(-1.67)	(-1.95)	(-1.88)
Constant	3.1828***	3.2208***	3.1469***	3.3218***	3.2653***	3.0677***	3.2428***	3.2467***	3.2884***	3.2851***
	(-11.61)	(-12.33)	(-11.8)	(-12.62)	(-11.79)	(-11.58)	(-11.67)	(-11.86)	(-12.01)	(-12.32)
No. Of Observations	1116	1116	1116	1116	1116	1116	1116	1116	1116	1116
R-Squared	0.366	0.356	0.327	0.342	0.333	0.33	0.327	0.333	0.329	0.332
F Statistic	63.886	101.985	107.686	115.177	92.338	109.202	108.086	92.08	108.845	110.476

fuels against the consumption of renewable energy.

5.6. Technology, governance, and carbon emission in Sub-Sahara Africa (full sample)

Table 8 reports the parameter estimates of the nexus between technology innovation, Governance, and renewable carbon emission in Sub-Sahara Africa. The regression output revealed that mobile cellular subscription (lnTI) as a proxy for technology innovation is inversely related to carbon emission while internet penetration is positively related to the carbon emission. This is indicated by estimated coefficients of lnTI and lnTI1 in all the estimated models for the full sample of 46 Sub-Sahara countries. Similarly, the coefficients of all the control variables – renewable energy consumption (lnREN), and GDP per capita (lnY) are negative and statistically significant, indicating an inverse relationship between the consumption of renewable energy, as well as GDP per capita, and carbon emission. Increase in income per capita may bring about demand for better environment and the consumption of clean energy, leading to reduction in carbon emission.

In the case of the governance indicators, the parameter estimates vary by the models. When all the indicators were included together, the estimates in column 1 revealed that government effectiveness (lnGE), and political stability (lnPS) are positively and significantly related to CO_2 while regulatory quality (lnRG) and rule of law (lnRUL) have significant negative impact on CO_2 while other governance indicators (lnVOA, and lnCC) are statistically insignificant. However, when governance indicators were included in separate models, the estimates of all the governance indicators are negative except the coefficient of political stability (lnPS), which positive. This implies political stability enhances CO_2 emission while other components of Governance are inversely associated with the carbon emission. The plausible explanation for this result is provided under the discussion of findings in this study.

5.7. Robustness checks (regression results of middle-income, and lower-income subsamples)

To check the robustness of the estimates of all the models, the estimates of the subsamples of middle-income and lower-income SSA countries are reported in Tables 9–14 for the clean energy and CO_2 models. The estimation is done for the renewable energy and CO_2 models by the two income (middle-income, and lower income) groups with different categories of the governance indicators (economic Governance, political Governance, and institutional Governance). The results show that findings concerning the nexus between technology innovation, Governance, and renewable energy consumption and CO_2 emission established in this study are robust and consistent across the subsamples of middle-income, and lower income SSA countries considered in this study. The negative impact of mobile cellular subscriptions on renewable energy consumption and CO_2 and the positive impact of internet penetration (coverage) on renewable energy consumption and CO_2 cut across all the subsamples. Similarly, the significant negative impact of the governance indicators and the control variables on both dependent variables are robust to the different subsamples. Hence, the findings of this study are robust and reliable for policy inferences. However, the magnitude of the effect of the technology innovation, and Governance on renewable energy consumption and carbon emission vary by the income groups and the category of Governance in SSA, which aligns studies by (Baye et al., 2021; Omri et al., 2022).

The current study provides interesting insights concerning the between technology innovation, Governance, and SDGs goal 7 (clean energy) and 13 (climate action). The findings robustly reveled an inverse nexus between both goals and mobile cellular subscriptions and positive association between internet penetration and both goals. We further established from the empirical evidence that the

Table 9
2SLS Results using sustainable Development goal 7 (Renewable energy) under parameters of Economic Governance.

	Dependent variable: Renewable energy consumption					
	Middle Income			Lower Income		
	Economic Governance			Economic Governance		
	EG	lnGE	lnRG	EG	lnGE	lnRG
lnTI	−0.2220***	−0.2205***	−0.2413***	−0.2115***	−0.1947***	−0.2122***
	(-5.72)	(-5.64)	(-6.21)	(-6.66)	(-6.21)	(-6.89)
lnTI1	0.0070***	0.0067***	0.0074***	0.0001	−0.0003	0.0001
	(-4.71)	(-4.48)	(-4.93)	(-0.12)	(-0.46)	(-0.14)
lnCo2	−0.6727***	−0.6269***	−0.7301***	−0.7528***	−0.7889***	−0.7520***
	(-9.93)	(-9.42)	(-10.96)	(-12.09)	(-12.90)	(-12.21)
lnGE	−0.0537***	−0.0867***		−0.0006	−0.0142***	
	(-3.69)	(-8.82)		(-0.09)	(-3.69)	
lnRG	−0.0374***		−0.0709***	−0.0203***		−0.0208***
	(-3.05)		(-8.55)	(-2.66)		(-4.57)
lnY	−0.6378***	−0.6483***	−0.6350***	−0.9239***	−0.8704***	−0.9248***
	(-16.38)	(-16.60)	(-16.14)	(-9.32)	(-8.92)	(-9.38)
Constant	13.2464***	13.2828***	13.3757***	16.2494***	15.6949***	16.2596***
	(-38.87)	(-38.72)	(-39.04)	(-17.13)	(-16.86)	(-17.3)
No. Of Observations	595	595	595	521	521	521
R-Squared	0.616	0.61	0.607	0.499	0.492	0.499
F Statistic	156.954	183.878	181.714	85.309	99.77	102.567

Note: *p < 0.05, **p < 0.01, ***p < 0.001, (.) is t-statistics.

Table 10
2SLS Results using sustainable Development goal 7 (Renewable energy) under parameters of Political Governance.

categorized	Dependent variable: Renewable energy consumption					
	Middle Income			Lower Income		
	Political Governance			Political Governance		
	PG	PS	VOA	PG	PS	VOA
lnTI	−0.1563***	−0.2214***	−0.1705***	−0.2208***	−0.2135***	−0.2081***
	(-4.05)	(-5.74)	(-4.27)	(-7.10)	(-6.92)	(-6.59)
lnTI1	0.0029*	0.0024	0.0060***	−0.0005	−0.0003	−0.0002
	(-1.92)	(-1.53)	(-4.04)	(-0.85)	(-0.61)	(-0.29)
lnCo2	−0.6145***	−0.6037***	−0.6697***	−0.7449***	−0.7354***	−0.7891***
	(-9.63)	(-9.14)	(-10.21)	(-11.87)	(-11.75)	(-12.49)
lnPS	−0.0600***	−0.0823***		−0.0081***	−0.0065***	
	(-6.71)	(-9.61)		(-4.60)	(-4.38)	
lnVOA	−0.0481***		−0.0668***	0.0074*		−0.0036
	(-6.56)		(-9.50)	(-1.69)		(-0.96)
lnY	−0.6889***	−0.5913***	−0.7772***	−0.8643***	−0.9319***	−0.8757***
	(-16.84)	(-14.99)	(-19.36)	(-8.09)	(-9.39)	(-8.04)
Constant	13.4465***	12.7636***	14.3985***	15.6959***	16.3145***	15.8066***
	(-37.79)	(-36.25)	(-42.56)	(-15.5)	(-17.25)	(-15.31)
No. Of Observations	595	595	595	521	521	521
R-Squared	0.644	0.618	0.617	0.500	0.497	0.48
F Statistic	177.211	190.467	189.469	85.706	101.913	94.908

Note: *p $<$ 0.05, **p $<$ 0.01, ***p $<$ 0.001, (.) is t-statistics.

Table 11
2SLS Results using sustainable Development goal 7 (Renewable energy) under parameters of Institutional Governance.

	Dependent variable: Renewable energy consumption					
	Middle Income			Lower Income		
	Institutional Governance			Institutional Governance		
	IG	CC	RUL	IG	CC	RUL
lnTI	−0.1287***	−0.1222***	−0.1754***	−0.2045***	−0.1969***	−0.2006***
	(-3.34)	(-3.18)	(-4.61)	(-6.61)	(-6.27)	(-6.54)
lnTI1	0.0037**	0.0033**	0.0055***	0.0001	−0.0002	0.0001
	(-2.56)	(-2.27)	(-3.81)	(-0.23)	(-0.45)	−0.11
lnCo2	−0.6281***	−0.6086***	−0.6854***	−0.7384***	−0.7715***	−0.7386***
	(-9.91)	(-9.70)	(-10.79)	(-12.03)	(-12.48)	(-12.03)
lnCC	−0.1003***	−0.1344***		0.0078	−0.0186***	
	(-4.92)	(-12.65)		(-0.94)	(-3.36)	
lnRUL	−0.0335*		−0.1053***	−0.0214***		−0.0178***
	(-1.96)		(-11.62)	(-4.19)		(-5.32)
lnY	−0.6718***	−0.6934***	−0.6212***	−0.8725***	−0.9056***	−0.8915***
	(-17.53)	(-18.85)	(-16.51)	(-8.86)	(-9.08)	(-9.25)
Constant	13.1646***	13.3357***	12.9044***	15.6857***	16.0325***	15.8588***
	(-39.74)	(-41.63)	(-38.7)	(-16.74)	(-16.91)	(-17.26)
No. Of Observations	595	595	595	521	521	521
R-Squared	0.655	0.652	0.64	0.507	0.49	0.506
F Statistic	185.768	221.086	209.799	87.976	98.892	105.422

Note: *p $<$ 0.05, **p $<$ 0.01, ***p $<$ 0.001, (.) is t-statistics.

magnitude of the negative impact of the mobile cellular subscriptions is greater than the positive impact of internet penetration on renewable energy consumption (clean energy) and carbon emission. Cumulatively, technology innovation hampers environmental sustainability in SSA. This finding is consistent with the first-order effect hypothesis, also known as the primary or direct effect of the ICT innovation. The hypothesis posits that the production, usage, and recycling of ICT equipment cause environmental degradation see (Alhassan, 2021; Asongu and Boateng, 2018; Higón et al., 2017; Jnr, 2020; Liu et al., 2022).

5.8. Significance of governance metrics findings under sub category of green governance

To improve policy execution and encourage inclusive Governance, particularly in developing nations, governance quality indicators are classified into three dimensions: political Governance, economic Governance, and institutional Governance. Establishing a policy regime that promotes green technology and growth may be stabilized by sound political arrangements, paving the way for sustainability (Ali et al., 2021; Tawiah et al., 2021). As a result, in response to the improvement in environmental quality, the required

Table 12
2SLS Results using sustainable Development goal 13 (Carbon emission) under parameters of Economic Governance.

	Dependent variable: Carbon emission					
	Middle Income			Lower Income		
	Economic Governance			Economic Governance		
	EG	lnGE	lnRG	EG	lnGE	lnRG
lnTI	−0.0773***	−0.0765***	−0.0711***	0.0273	0.0134	0.0138
	(-3.47)	(-3.33)	(-3.17)	−1.32	−0.66	−0.68
lnTI1	0.0030***	0.0027***	0.0030***	−0.0006*	−0.0004	−0.0005
	(-3.59)	(-3.13)	(-3.49)	(-1.82)	(-1.20)	(-1.33)
lnREN	−0.2135***	−0.2090***	−0.2319***	−0.2940***	−0.3096***	−0.2984***
	(-9.93)	(-9.42)	(-10.96)	(-12.09)	(-12.90)	(-12.21)
lnGE	0.0307***	−0.0054		−0.0114***	−0.0017	
	−3.74	(-0.89)		(-2.89)	(-0.69)	
lnRG	−0.0422***		−0.0246***	0.0148***		0.0039
	(-6.28)		(-5.06)	(-3.11)		(-1.34)
lnY	−0.0322	−0.0348	−0.043	−0.1237*	−0.1745***	−0.1429**
	(-1.22)	(-1.28)	(-1.62)	(-1.85)	(-2.67)	(-2.14)
Constant	3.0851***	3.0856***	3.2604***	3.9451***	4.5888***	4.2187***
	(-9.08)	(-8.8)	(-9.58)	(-5.46)	(-6.58)	(-5.85)
No. Of Observations	595	595	595	521	521	521
R-Squared	0.233	0.181	0.214	0.306	0.293	0.295
F Statistic	29.707	26.069	32.133	37.826	42.738	43.112

Note: *p < 0.05, **p < 0.01, ***p < 0.001, (.) is t-statistics.

Table 13
2SLS Results using sustainable Development goal 13 (Carbon emission) under parameters of Political Governance.

	Dependent variable: Carbon emission					
	Middle Income			Lower Income		
	Political Governance			Political Governance		
	PG	PS	VOA	PG	PS	VOA
lnTI	−0.0629***	−0.0778***	−0.0628***	0.0076	0.0159	0.005
	(-2.69)	(-3.39)	(-2.69)	(-0.38)	(-0.79)	(-0.25)
lnTI1	0.0027***	0.0026***	0.0026***	−0.0005	−0.0004	−0.0005
	−3.05	−2.87	−3.05	(-1.38)	(-1.02)	(-1.51)
lnREN	−0.2217***	−0.2059***	−0.2244***	−0.2890***	−0.2874***	−0.2945***
	(-9.63)	(-9.14)	(-10.21)	(-11.87)	(-11.75)	(-12.49)
lnPS	0.0023	−0.0023		0.001	0.0027***	
	(-0.41)	(-0.43)		(-0.93)	(-2.84)	
lnVOA	−0.0132***		−0.0127***	0.0071***		0.0085***
	(-2.92)		(-2.93)	(-2.6)		(-3.74)
lnY	−0.0692**	−0.0317	−0.0680**	−0.0499	−0.1110*	−0.053
	(-2.33)	(-1.17)	(-2.30)	(-0.71)	(-1.66)	(-0.75)
Constant	3.4305***	3.0468***	3.4342***	3.2833***	3.8377***	3.3546***
	(-9.28)	(-8.76)	(-9.3)	(-4.38)	(-5.31)	(-4.5)
No. Of Observations	595	595	595	521	521	521
R-Squared	0.192	0.18	0.192	0.312	0.303	0.311
F Statistic	23.302	25.923	27.968	38.939	44.88	46.568

Note: *p < 0.05, **p < 0.01, ***p < 0.001, (.) is t-statistics.

steps should be done to develop strong governance quality and strengthen green innovations. In order to achieve sustainable growth, it is imperative that emerging nations actively promote governance inclusiveness. Since all treaties must be implemented, all laws must be enforceable, and they fall under their purview. Effective mitigation of the negative effects of technology advancement that may not be in tangent with carbon neutrality may be also be addressed within the framework of green Governance.

The surprising findings may be interpreted from two viewpoints, both of which have policy consequences. (a) When economic prosperity is spread equitably across the population through improved education, better salaries, and improved health care (i.e., components of the Human Development Index), the average person has more opportunities to participate in production and consumption processes that are positively correlated with greenhouse gas emissions. (b) The findings indicate an inclusive governance that promotes all the metrics of good Governance is necessary to promote SDG 7, leading to SDG 13. A less prone to corruption and politically stable country would lead to investor confidence. Such investment could easily be to areas such as solar generation for electricity, a major need in SSA. This will also do well to encourage technological innovation, another preset for the green economy. In the long run, can easily attain SDG 13, (b) Good Governance is an essential but insufficient tool for reducing greenhouse gas emissions.

Table 14
2SLS Results using sustainable Development goal 13 (Carbon emission) under parameters of Institutional Governance.

	Dependent variable: Carbon emission					
	Middle Income			Lower Income		
	Institutional Governance			Institutional Governance		
	IG	CC	RUL	IG	CC	RUL
lnTI	−0.0730***	−0.0655***	−0.0626***	0.011	0.0097	0.0121
	(-3.15)	(-2.79)	(-2.74)	(-0.54)	(-0.48)	(-0.6)
lnTI1	0.0029***	0.0024***	0.0025***	−0.0004	−0.0004	−0.0005
	(-3.39)	(-2.74)	(-2.98)	(-1.24)	(-1.15)	(-1.30)
lnREN	−0.2279***	−0.2263***	−0.2408***	−0.2975***	−0.3008***	−0.2971***
	(-9.91)	(-9.70)	(-10.79)	(-12.03)	(-12.48)	(-12.03)
lnCC	0.0278**	−0.0163**		0.002	0.0044	
	(-2.23)	(-2.24)		(-0.37)	(-1.26)	
lnRUL	−0.0439***		−0.0254***	0.002		0.0029
	(-4.32)		(-4.33)	(-0.61)		(-1.35)
lnY	−0.0272	−0.0512*	−0.0484*	−0.1451**	−0.1449**	−0.1495**
	(-0.96)	(-1.81)	(-1.80)	(-2.17)	(-2.17)	(-2.28)
Constant	3.0834***	3.2954***	3.3246***	4.2470***	4.2673***	4.2848***
	(-8.53)	(-9.07)	(-9.61)	(-5.94)	(-5.98)	(-6.06)
No. Of Observations	595	595	595	521	521	521
R-Squared	0.212	0.187	0.205	0.295	0.295	0.295
F Statistic	26.37	27.103	30.449	35.897	43.053	43.121

Note: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, (.) is t-statistics.

This is due in part to the low governance standards in most SSA nations and the possibility of supplementing the associated governance processes with other variables that are exogenous to pollutant emissions. Hence improvement in the use of technological input friendly to the environment is necessary and prudent.

6. Conclusion and policy implications

The chase for cleaner energy options seems a priority for most economies, and the African blocs is no exception to this pursuit. However, this laudable pursuit is challenged by the continent's anthropogenic activities which stem from its exploration and exploitation of her natural resources and reliant on fossil-fuel energy sources. It is on this premise that the current study examined the nexus between energy consumption (SDG-7), climate action (SDG-13), and economic growth (SDG-8) while controlling for role of government apparatus like voice of accountability, rule of law, control of corruption and technology innovation in a balanced panel of selected African blocs and into further strata for insightful policy formulations. Empirical study leverages recent and robust panel econometrics techniques.

The current study provides interesting insights concerning the between technology innovation, Governance, and SDGs goal 7 (clean energy) and 13 (climate action). The findings robustly reveled an inverse nexus between both goals and mobile cellular subscriptions, and positive association between internet penetration and both goals. We further established from the empirical evidence that the magnitude of the negative impact of the mobile cellular subscriptions is greater than the positive impact of the internet penetration on renewable energy consumption (clean energy) and carbon emission. Cumulatively, technology innovation hampers environmental sustainability in SSA. This finding is consistent with the first-order effect hypothesis also known as primary or direct effect of the ICT innovation. The hypothesis posits that ICT equipment production, usage and recycling cause environmental degradation. From a policy perspective, this suggest that environmental pollution effect associated with the lifecycle of ICT products. Sub-Sahara Africa is a huge market for ICT products, particularly smartphones, phone accessories, and related products. An increase in mobile subscriptions will increase the demand for ICT products – smartphones, SIM cards, recharge cards et cetera. Also, the increase in the demand for ICT products will lead to a rise in the consumption of nonrenewable energy (fossil fuels) due to an increase in ICT-related economic activities and an increase in demand for electricity, which is mostly generated through nonrenewable sources. The rise in the consumption of nonrenewable energy, will result in the reduction in the proportion of renewable energy consumption. Hence, the mobile cellular subscription is inversely related to the consumption of clean energy in SSA. The positive association between internet penetration and renewable energy consumption, and the negative nexus between mobile subscriptions CO_2 confirm the proposition of the second-order effect also referred to secondary or indirect effect that technological innovation enhances energy efficiency, which reduces environmental degradation. The increase in internet coverage increases the demand for electricity and foster the use of energy-efficient gargets and clean (renewable) energy, especially Solar PV, and reduces pollution across all parts of SSA.

Another interesting finding is that the magnitude of technology innovation's negative impact is greater than the positive impact. This supports the Jevon's paradox (rebound effect), which postulated that an increase in efficiency use of the resource will generate an increase in the consumption of the resource rather than decrease in its consumption. In this context, the efficiency gains of technological innovation will increase fossil-based energy consumption, which will offset the positive effect of internet penetration on renewable energy consumption.

Equally, this study provides empirical evidence of negative nexus between governance indicators and the SDGs goal 7 and 13 confirms the thesis that improvement in the quality of Governance spurs economic activities and infrastructural development, which can be associated with huge consumption of fossil fuel, and lower consumption of renewable energy. The growth-promoting effect of the institutions can equally increase environmental consciousness and raise the demand for cleaner energy, thereby reducing carbon emissions. This is plausible because none of the governance indicators focuses on environmental regulation. Thus, improvement in Governance enhances economic growth and development, which may promotes the consumption of nonrenewable energy particularly in SSA. Therefore, this study provides strong empirical evidence that Governance plays a vital role in determining the attainment of sustainable development goals 7 (clean energy) and 13 (climate action).

Conclusively, as a requirement to accomplish the SDG-7, 8 and 13 which this study seek to bridge especially for the middle and low-income divide in SSA, there is a need to mitigate climate change and its impact in 2030 for the study blocs. There is need for sustainable and decent economic growth and productivity via decarbonization, innovation in research and development (R&D) technologies, technological advancement, diversification. Additionally, the effect of fossil-fuel based energy (non-renewable energy) consumption and economic growth on environmental pollution can be mitigated via improving energy efficiency and pragmatic energy regulations through gradual transition to cleaner alternative energies (renewables). The role of institution should be strength via energy legislation that decouple economic growth from emission via environmental tax pollution laws. As a limitation for the current study which focuses on SSA, future study can examine the theme for other blocs and consider other drivers of emission does not account for in the present study.

Authors contributions

Elvis Kwame Ofori : Conceptualization , Writing, Methodology, Software, Literature review, Visualization, Results , Abdulkareem Alhassan: Conceptualization, Methodology, Software, Literature review. Ilhan Ozturk: Supervision, Writing, Reviewing and Editing, Obadiah Jonathan Gimba: Discussion ,Literature review, Visualization, Festus Victor Bekun: Data curation, Writing, Visualization, Results.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix

Sample Adequacy Test

KMO and Bartlett's test	
Kaiser–Meyer–Olkin measure of sampling adequacy	0.833
Bartlett test of sphericity	
Chi-square	8134.716
Degrees of freedom	55
p-value	0.000

Sub countries

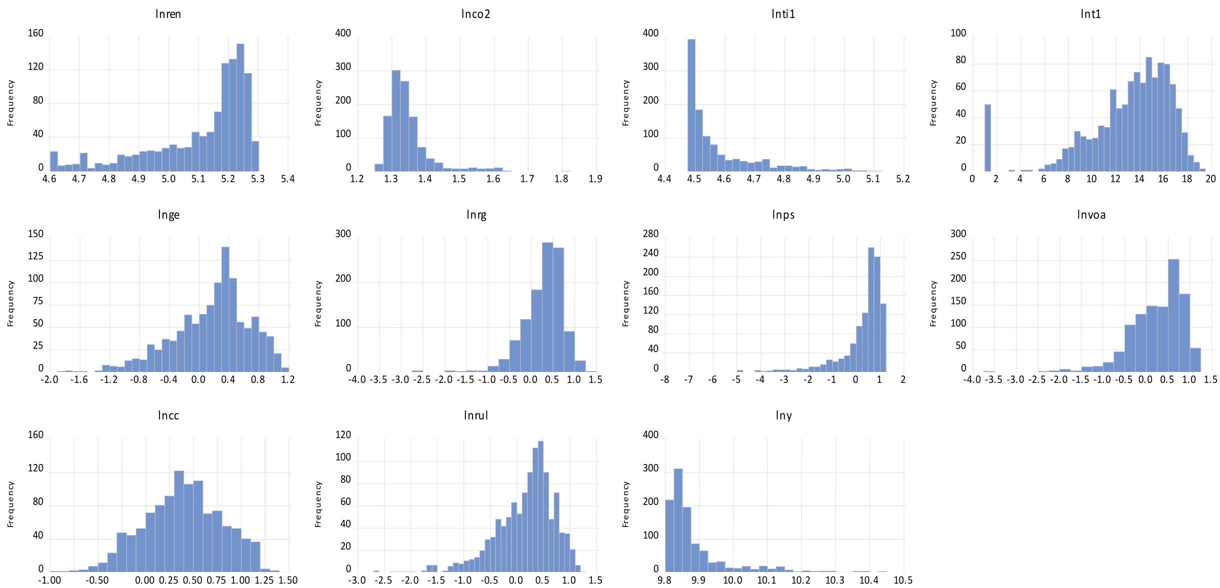
Middle income (24)	Lower-income (21)
Angola	Burkina Faso
Benin	Burundi
Botswana	Central African Republic
Cabo Verde	Chad
Cameroon	Congo, Dem. Rep.
Comoros	Ethiopia
Congo, Rep.	Gambia, The
Cote d'Ivoire	Guinea
Equatorial Guinea	Guinea-Bissau
Eswatini	Liberia
Gabon	Madagascar

(*continued on next page*)

(*continued*)

Middle income (24)	Lower-income (21)
Ghana	Malawi
Kenya	Mali
Lesotho	Mozambique
Mauritania	Niger
Mauritius	Rwanda
Namibia	Sierra Leone
Nigeria	Sudan
Sao Tome and Principe	Togo
Senegal	Uganda
Seychelles	Zambia
South Africa	
Tanzania	
Zimbabwe	

Distribution table of variables



References

Abbasi, K.R., Shahbaz, M., Zhang, J., Irfan, M., Alvarado, R., 2022. Analyze the environmental sustainability factors of China: the role of fossil fuel energy and renewable energy. Renew. Energy 187, 390–402.

Adebayo, T.S., 2022. Renewable energy consumption and environmental sustainability in Canada: does political stability make a difference? Environ. Sci. Pollut. Control Ser. https://doi.org/10.1007/s11356-022-20008-4.

Adenle, A.A., 2020. Assessment of solar energy technologies in Africa-opportunities and challenges in meeting the 2030 agenda and sustainable development goals. Energy Pol. 137, 111180 https://doi.org/10.1016/j.enpol.2019.111180.

Adenle, A.A., Azadi, H., Arbiol, J., 2015. Global assessment of technological innovation for climate change adaptation and mitigation in developing world. J. Environ. Manag. 161, 261–275.

Adewale Alola, A., Ozturk, I., Bekun, F.V., 2021. Is clean energy prosperity and technological innovation rapidly mitigating sustainable energy-development deficit in selected sub-Saharan Africa? A myth or reality. Energy Pol. 158, 112520 https://doi.org/10.1016/j.enpol.2021.112520.

Ahl, A., Goto, M., Yarime, M., Tanaka, K., Sagawa, D., 2022. Challenges and opportunities of blockchain energy applications: interrelatedness among technological, economic, social, environmental, and institutional dimensions. Renew. Sustain. Energy Rev. 166, 112623.

Ahmed, S.F., Kumar, P.S., Kabir, M., Zuhara, F.T., Mehjabin, A., Tasannum, N., Hoang, A.T., Kabir, Z., Mofijur, M., 2022. Threats, Challenges and Sustainable Conservation Strategies for Freshwater Biodiversity. Environmental Research, 113808.

Akinyemi, O., Okoli, I., Chidozie, F., 2021. Institutional framework and the transition to green growth for sustainable development in Africa. *African Journal of Business and Economic Research*, *2021*(si1), 47.

Alhassan, H., 2021. The effect of agricultural total factor productivity on environmental degradation in sub-Saharan Africa. Scientific African 12, e00740.

Ali, E.B., Anufriev, V.P., Amfo, B., 2021. Green economy implementation in Ghana as a road map for a sustainable development drive: a review. Scientific African 12, e00756.

Alola, A.A., Onifade, S.T., 2022. Energy innovations and pathway to carbon neutrality in Finland. Sustain. Energy Technol. Assessments 52, 102272.

Altıntaş, H., Kassouri, Y., 2020. The impact of energy technology innovations on cleaner energy supply and carbon footprints in Europe: a linear versus nonlinear approach. J. Clean. Prod. 276, 124140.
Amesho, K.T., 2019. Financing Renewable Energy in Namibia: a Fundamental Key Challenge to the Sustainable Development Goal 7: Ensuring Access to Affordable, Reliable, Sustainable and Modern Energy for All, 670216917.
Anwar, M.A., Zhang, Q., Asmi, F., Hussain, N., Plantinga, A., Zafar, M.W., Sinha, A., 2022. Global perspectives on environmental kuznets curve: a bibliometric review. Gondwana Res. 103, 135–145.
Arafath, J., 2022. Challenges ahead to sustainable development in Bangladesh: a concern for future generation. development 14, 21.
Arora, N.K., Mishra, I., 2021. COP26: More Challenges than Achievements. Springer, pp. 1–4.
Asongu, S., Boateng, A., 2018. In: Introduction to Special Issue: Mobile Technologies and Inclusive Development in Africa, vol. 19. Taylor & Francis, pp. 297–301.
Asongu, S.A., Nwachukwu, J.C., 2017. Quality of Growth Empirics: comparative gaps, benchmarking and policy syndromes. J. Pol. Model. 39 (5), 861–882. https://doi.org/10.1016/j.jpolmod.2017.08.005.
Awan, U., 2022. Industrial ecology in support of sustainable development goals. In: Responsible Consumption and Production. Springer, pp. 370–380.
Baltagi, B.H., Feng, Q., Kao, C., 2012. A Lagrange Multiplier test for cross-sectional dependence in a fixed effects panel data model. J. Econom. 170 (1), 164–177.
Baye, R.S., Olper, A., Ahenkan, A., Musah-Surugu, I.J., Anuga, S.W., Darkwah, S., 2021. Renewable energy consumption in Africa: evidence from a bias corrected dynamic panel. Sci. Total Environ. 766, 142583.
Biermann, F., Hickmann, T., Sénit, C.-A., 2022. The Political Impact of the Sustainable Development Goals: Transforming Governance through Global Goals? Cambridge University Press.
Boeing, P., Eberle, J., Howell, A., 2022. The impact of China's R&D subsidies on R&D investment, technological upgrading and economic growth. Technol. Forecast. Soc. Change 174, 121212.
Bollen, K.A., 1996. An alternative two stage least squares (2SLS) estimator for latent variable equations. Psychometrika 61 (1), 109–121.
Bradu, P., Biswas, A., Nair, C., Sreevalsakumar, S., Patil, M., Kannampuzha, S., Mukherjee, A.G., Wanjari, U.R., Renu, K., Vellingiri, B., 2022. Recent advances in green technology and Industrial Revolution 4.0 for a sustainable future. Environ. Sci. Pollut. Control Ser. 1–32.
Breusch, T.S., Pagan, A.R., 1980. The Lagrange multiplier test and its applications to model specification in econometrics. Rev. Econ. Stud. 47 (1), 239–253.
Burhan, M., Singh, A.K., Jain, S.K., 2017. Patents as proxy for measuring innovations: a case of changing patent filing behavior in Indian public funded research organizations. Technol. Forecast. Soc. Change 123, 181–190. https://doi.org/10.1016/j.techfore.2016.04.002.
Cafaro, P., 2014. Avoiding catastrophic climate change: why technological innovation is necessary but not sufficient. In: Ethics and Emerging Technologies. Springer, pp. 424–438.
Chakravorty, U., Pelli, M., Gupta, R., 2022. The Economics of Rural Energy Use in Developing Countries.
Chambers, D., Munemo, J., 2019. Regulations, institutional quality and entrepreneurship. J. Regul. Econ. 55 (1), 46–66.
Cheng, Y., Awan, U., Ahmad, S., Tan, Z., 2021. How do technological innovation and fiscal decentralization affect the environment? A story of the fourth industrial revolution and sustainable growth. Technol. Forecast. Soc. Change 162, 120398.
Chien, F., Sadiq, M., Nawaz, M.A., Hussain, M.S., Tran, T.D., Le Thanh, T., 2021. A step toward reducing air pollution in top Asian economies: The role of green energy, eco-innovation, and environmental taxes. Journal of environmental management 297, 113420. Chicago.
Chirambo, D., 2018. Towards the achievement of SDG 7 in sub-Saharan Africa: creating synergies between Power Africa, Sustainable Energy for All and climate finance in-order to achieve universal energy access before 2030. Renew. Sustain. Energy Rev. 94, 600–608.
Dabbous, A., Tarhini, A., 2021. Does sharing economy promote sustainable economic development and energy efficiency? Evidence from OECD countries. Journal of Innovation & Knowledge 6 (1), 58–68.
Donella, H., Meadows, D.L., Randers, J., Behrens III, W.W., 1972. The Limits to Growth. Universe, New York.
Eslami, H., Najem, S., Abi Ghanem, D., Ahmad, A., 2021. The potential of urban distributed solar energy in transition economies: the case of Beirut city. J. Environ. Manag. 285, 112121.
Fotio, H.K., Nchofoung, T.N., Asongu, S.A., 2022. Financing renewable energy generation in SSA: Does financial integration matter? Renewable Energy 201, 47–59.
Freeman, C., 2013. Economics of Industrial Innovation. Routledge.
Fuller, R., Landrigan, P.J., Balakrishnan, K., Bathan, G., Bose-O'Reilly, S., Brauer, M., Yan, C., 2022. Pollution and health: a progress update. The Lancet Planetary Health 6 (6), e535–e547.
Ferreira, P., Almeida, D., Dionísio, A., Bouri, E., Quintino, D., 2022. Energy markets–Who are the influencers? Energy 239, 121962.
Ge, L., Zhao, H., Yang, J., Yu, J., He, T., 2022. Green finance, technological progress, and ecological performance—evidence from 30 Provinces in China. Environ. Sci. Pollut. Control Ser. 1–20.
Goyeneche, O.Y.R., Ramirez, M., Schot, J., Arroyave, F., 2022. Mobilizing the transformative power of research for achieving the Sustainable Development Goals. Res. Pol. 51 (10), 104589.
Grossman, G.M., Helpman, E., 1993. Innovation and Growth in the Global Economy. MIT press.
Gyamfi, B.A., Agozie, D.Q., Bekun, F.V., 2022. Can technological innovation, foreign direct investment and natural resources ease some burden for the BRICS economies within current industrial era? Technol. Soc. 70, 102037 https://doi.org/10.1016/j.techsoc.2022.102037.
Haldar, A., Sethi, N., 2022. Environmental effects of Information and Communication Technology-Exploring the roles of renewable energy, innovation, trade and financial development. Renew. Sustain. Energy Rev. 153, 111754.
Hervieux, C., McKee, M.C., 2022. Mapping SDGs in sub-saharan Africa: highlighting system effects. Social Impact Measurement for a Sustainable Future 279–299.
Higón, D.A., Gholami, R., Shirazi, F., 2017. ICT and environmental sustainability: a global perspective. Telematics Inf. 34 (4), 85–95.
Ibrahim, R.L., Julius, O.O., Nwokolo, I.C., Ajide, K.B., 2022. The role of technology in the non-renewable energy consumption-quality of life nexus: insights from sub-Saharan African countries. Econ. Change Restruct. 55 (1), 257–284.
Javed, A., Rapposelli, A., Khan, F., Javed, A., 2023. The impact of green technology innovation, environmental taxes, and renewable energy consumption on ecological footprint in Italy: fresh evidence from novel dynamic ARDL simulations. Technol. Forecast. Soc. Change 191, 122534. https://doi.org/10.1016/j.techfore.2023.122534.
Jian, L., Chuimin, K., Jijian, Z., Yusheng, K., Ntarmah, A.H., 2022. The relationship between economic growth and environmental degradation: could West African countries benefit from EKC hypothesis? Environ. Sci. Pollut. Control Ser. 1–19.
Jnr, B.A., 2020. Examining the role of green IT/IS innovation in collaborative enterprise-implications in an emerging economy. Technol. Soc. 62, 101301.
Lin, B., Sai, R., 2022. Sustainable transitioning in Africa: a historical evaluation of energy productivity changes and determinants. Energy 250, 123833.
Lin, B., Zhu, J., 2019. The role of renewable energy technological innovation on climate change: empirical evidence from China. Sci. Total Environ. 659, 1505–1512.
Liu, H., Liang, D., 2013. A review of clean energy innovation and technology transfer in China. Renew. Sustain. Energy Rev. 18, 486–498.
Liu, J., Quddoos, M.U., Akhtar, M.H., Amin, M.S., Tariq, M., Lamar, A., 2022. Digital technologies and circular economy in supply chain management: in the era of COVID-19 pandemic. Operations Management Research 1–16.
Ma, Q., Tariq, M., Mahmood, H., Khan, Z., 2022. The nexus between digital economy and carbon dioxide emissions in China: the moderating role of investments in research and development. Technol. Soc. 68, 101910.
Mensah, C.N., Long, X., Dauda, L., Boamah, K.B., Salman, M., Appiah-Twum, F., Tachie, A.K., 2019. Technological innovation and green growth in the organization for economic cooperation and development economies. J. Clean. Prod. 240, 118204.
Mohsin, M., Taghizadeh-Hesary, F., Iqbal, N., Saydaliev, H.B., 2022. The role of technological progress and renewable energy deployment in green economic growth. Renew. Energy 190, 777–787.
Moshood, T.D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M.H., AbdulGhani, A., Kumar, S., 2022. Green product innovation: a means towards achieving global sustainable product within biodegradable plastic industry. J. Clean. Prod., 132506
Mustafa, M., Ghazali, F., Yuniza, M.E., 2022. Governance interventions in providing affordable, reliable, sustainable, and modern energy in the ASEAN region (Goal 7). In: Good Governance and the Sustainable Development Goals in Southeast Asia. Routledge, pp. 84–97.

Obobisa, E.S., Chen, H., Mensah, I.A., 2022. The impact of green technological innovation and institutional quality on CO2 emissions in African countries. Technol. Forecast. Soc. Change 180, 121670.
Ofori, E.K., Appiah-Opoku, S., 2023. Sustainable Development Goals in BRICS and G7 Countries: Increasing Accomplishments through Policy Synergies in Four Dimensions. Sustainable Development. https://doi.org/10.1002/sd.2653. *n/a*(n/a).
Ofori, E.K., Li, J., Gyamfi, B.A., Opoku-Mensah, E., Zhang, J., 2023a. Green industrial transition: leveraging environmental innovation and environmental tax to achieve carbon neutrality. Expanding on STRIPAT model. J. Environ. Manag. 343, 118121 https://doi.org/10.1016/j.jenvman.2023.118121.
Ofori, E.K., Li, J., Radmehr, R., Zhang, J., Shayanmehr, S., 2023b. Environmental consequences of ISO 14001 in European economies amidst structural change and technology innovation: insights from green governance dynamism. J. Clean. Prod., 137301 https://doi.org/10.1016/j.jclepro.2023.137301.
Ofori, E.K., Onifade, S.T., Ali, E.B., Alola, A.A., Zhang, J., 2023c. Achieving carbon neutrality in post COP26 in BRICS, MINT, and G7 economies: the role of financial development and governance indicators. J. Clean. Prod. 387, 135853 https://doi.org/10.1016/j.jclepro.2023.135853.
Ofori, E.K., Zhang, J., Nyantakyi, G., Hayford, I.S., Tergu, C.T., 2023d. Impact of Covid-19 on Environmental Sustainability: A Bibliometric Analysis. https://doi.org/10.1002/sd.2554.
Olabi, A., Abdelkareem, M.A., 2022. Renewable energy and climate change. Renew. Sustain. Energy Rev. 158, 112111.
Omri, A., 2020. Formal versus informal entrepreneurship in emerging economies: the roles of governance and the financial sector. J. Bus. Res. 108, 277–290. https://doi.org/10.1016/j.jbusres.2019.11.027.
Omri, A., Hadj, T.B., 2020. Foreign investment and air pollution: do good governance and technological innovation matter? Environ. Res. 185, 109469.
Omri, A., Omri, H., Slimani, S., Belaid, F., 2022. Environmental degradation and life satisfaction: do governance and renewable energy matter? Technol. Forecast. Soc. Change 175, 121375.
Onifade, S.T., Alola, A.A., 2022a. Energy Transition and Environmental Quality Prospects in Leading Emerging Economies: the Role of Environmental-Related Technological Innovation. https://doi.org/10.1002/sd.2346.
Onifade, S.T., Alola, A.A., 2022b. Energy Transition and Environmental Quality Prospects in Leading Emerging Economies: the Role of Environmental-related Technological Innovation. Sustainable Development.
Pata, U.K., 2021. Linking renewable energy, globalization, agriculture, CO2 emissions and ecological footprint in BRIC countries: a sustainability perspective. Renew. Energy 173, 197–208.
Patel, S.H., Pinckney, T.C., Jaeger, W.K., 1995. Smallholder wood production and population pressure in East Africa: evidence of an environmental Kuznets curve? Land Econ. 516–530.
Persyn, D., Westerlund, J., 2008. Error-correction–based cointegration tests for panel data. STATA J. 8 (2), 232–241.
Pesaran, M.H., 2004. General Diagonist Tests for Cross Section Dependence in Panels.
Pesaran, M.H., 2007. A simple panel unit root test in the presence of cross-section dependence. J. Appl. Econom. 22 (2), 265–312.
Pesaran, M.H., Ullah, A., Yamagata, T., 2008. A bias-adjusted LM test of error cross-section independence. Econom. J. 11 (1), 105–127.
Pesaran, M.H., Vanessa Smith, L., Yamagata, T., 2013. Panel unit root tests in the presence of a multifactor error structure. J. Econom. 175 (2), 94–115. https://doi.org/10.1016/j.jeconom.2013.02.001.
Pesaran, M.H., Yamagata, T., 2008. Testing slope homogeneity in large panels. J. Econom. 142 (1), 50–93.
Phillips, C.A., Caldas, A., Cleetus, R., Dahl, K.A., Declet-Barreto, J., Licker, R., Merner, L.D., Ortiz-Partida, J.P., Phelan, A.L., Spanger-Siegfried, E., Talati, S., Trisos, C. H., Carlson, C.J., 2020. Compound climate risks in the COVID-19 pandemic. Nat. Clim. Change 10 (7), 586–588. https://doi.org/10.1038/s41558-020-0804-2.
Płonka, M., Kożuch, M., Stanienda, J., 2022. The Fourth Industrial Revolution and contemporary technological, economic and cultural megatrends. In: Public Goods and the Fourth Industrial Revolution. Routledge, pp. 7–34.
Polyviou, A., Zamani, E.D., 2022. Are we nearly there yet? A desires & realities framework for europe's ai strategy. Inf. Syst. Front 1–17.
Rasulov, J., 2022. Technological Innovation and Unemployment across Sweden: An analysis based on patent counts. p. 56.
Rout, S.K., Gupta, M., Sahoo, M., 2022. The role of technological innovation and diffusion, energy consumption and financial development in affecting ecological footprint in BRICS: an empirical analysis. Environ. Sci. Pollut. Control Ser. 29 (17), 25318–25335. https://doi.org/10.1007/s11356-021-17734-6.
Sachs, J.D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., Rockström, J., 2019. Six transformations to achieve the sustainable development goals. Nat. Sustain. 2 (9), 805–814.
Santos, F.D., Ferreira, P.L., Pedersen, J.S.T., 2022. The climate change challenge: a review of the barriers and solutions to deliver a paris solution. Climate 10 (5), 75.
Shan, S., Genç, S.Y., Kamran, H.W., Dinca, G., 2021. Role of green technology innovation and renewable energy in carbon neutrality: a sustainable investigation from Turkey. J. Environ. Manag. 294, 113004.
Sharma, R., Shahbaz, M., Kautish, P., Vo, X.V., 2021. Analyzing the impact of export diversification and technological innovation on renewable energy consumption: evidences from BRICS nations. Renew. Energy 178, 1034–1045.
Shulla, K., Voigt, B.-F., Cibian, S., Scandone, G., Martinez, E., Nelkovski, F., Salehi, P., 2021. Effects of COVID-19 on the sustainable development goals (SDGs). Discover Sustainability 2 (1), 1–19.
Silveira, F., da Matta Machado Fernandes, L., Paes-Sousa, R., 2022. The sustainable health Agenda in the Americas: pre-pandemic gaps and 2030 estimates of the SDGs indicators. PLoS One 17 (6), e0270301.
Soumonni, O.C., Soumonni, O.Y., 2011. Promoting West African ownership of the power sector: alternative financing for distributed generation of renewable electricity. J. Afr. Bus. 12 (3), 310–329.
Su, C.-W., Naqvi, B., Shao, X.-F., Li, J.-P., Jiao, Z., 2020. Trade and technological innovation: the catalysts for climate change and way forward for COP21. J. Environ. Manag. 269, 110774.
Su, W., Xu, X., Li, Y., Martinez-Lopez, F.J., Li, L., 2018. Technological innovation: a case study of mobile internet information technology applications in community management. J. Global Inf. Manag. 26 (2), 193–203.
Sun, H., Edziah, B.K., Kporsu, A.K., Sarkodie, S.A., Taghizadeh-Hesary, F., 2021. Energy efficiency: the role of technological innovation and knowledge spillover. Technol. Forecast. Soc. Change 167, 120659.
Syed, Q.R., Bouri, E., 2021. Impact of economic policy uncertainty on CO2 emissions in the US: evidence from bootstrap ARDL approach. J. Publ. Aff., e2595
Tavanti, M., 2023. Technology innovations for the SDGs. In: Developing Sustainability in Organizations: A Values-Based Approach. Springer, pp. 389–404.
Tawiah, V., Zakari, A., Adedoyin, F.F., 2021. Determinants of green growth in developed and developing countries. Environ. Sci. Pollut. Control Ser. 28 (29), 39227–39242.
Tilstra, M.H., 2022. Global Problems with Local Impacts: Exploring the Health Impacts of Climate Change and Air Pollution in Older Adults and Immigrants Living in Canada.
Ullah, S., Adebayo, T.S., Irfan, M., Abbas, S., 2023. Environmental quality and energy transition prospects for G-7 economies: the prominence of environment-related ICT innovations, financial and human development. J. Environ. Manag. 342, 118120.
Usman, M., Balsalobre-Lorente, D., 2022. Environmental concern in the era of industrialization: can financial development, renewable energy and natural resources alleviate some load? Energy Pol. 162, 112780 https://doi.org/10.1016/j.enpol.2022.112780.
Usman, M., Radulescu, M., 2022. Examining the role of nuclear and renewable energy in reducing carbon footprint: does the role of technological innovation really create some difference? Sci. Total Environ. 841, 156662.
Wang, J., Ma, F., Bouri, E., Zhong, J., 2022a. Volatility of clean energy and natural gas, uncertainty indices, and global economic conditions. Energy Econ. 108, 105904.
Wang, Q., Qu, J., Wang, B., Wang, P., Yang, T., 2019. Green technology innovation development in China in 1990–2015. Science of the Total Environment 696, 134008.
Wang, Q., Wang, X., Li, R., 2022b. Does urbanization redefine the environmental Kuznets curve? An empirical analysis of 134 Countries. Sustain. Cities Soc. 76, 103382.
Wang, Z.-a., Zheng, C., 2022. Is technological innovation the cure for overcapacity? Exploring mediating and moderating mechanisms. J. Bus. Res. 147, 348–361.

Westerlund, J., 2007. Testing for error correction in panel data. Oxf. Bull. Econ. Stat. 69 (6), 709–748.
Zang, S.M., Benjenk, I., Breakey, S., Pusey-Reid, E., Nicholas, P.K., 2021. The intersection of climate change with the era of COVID-19. Publ. Health Nurs. 38 (2), 321–335.
Zhang, W., Li, G., Guo, F., 2022. Does carbon emissions trading promote green technology innovation in China? Appl. Energy 315, 119012. https://doi.org/10.1016/j.apenergy.2022.119012.