Journal of the Knowledge Economy
https://doi.org/10.1007/s13132-024-01894-0

The Impact of Energy Consumption, Financial Development, and Foreign Direct Investment on Environmental Quality: Fresh Insights from Static and Dynamic Panel Models

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Received: 3 April 2022 / Accepted: 13 February 2024

Abstract

The current global trend shows that there is a tremendous increase in CO_2 emission and that the level of emission is increasing with various development factors such as consumption of non-renewable energy, financial development, and FDI. However, very few studies have examined the impact of development factors that increase CO_2 emissions, especially for African Countries. Therefore, this study contributes to the existing literature by examining the impact of these development factors (i.e., renewable energy consumption, non-renewable energy consumption, FDI, and financial development) on CO_2 emission while also considering the importance of institutional quality and technical advancement in African countries. The study also addresses the issues of whether institutional quality and technological advancement have a role in protecting the environment and achieving faster economic growth. A panel between 1996 to 2020 and a model for estimation is used. Results of the analysis indicate that using renewable energy is a fundamental tool in promoting sustainable development by reducing environmental pollution. However, Financial developments and Foreign Direct investment positively impact CO_2 emissions. Nevertheless, the majority of the institutional quality estimates are significant for reducing environmental pollution. Technological innovation is revealed as environmental degradation reducer and encourages sustainable growth. The findings call for African policymakers to formulate policies that encourage the use of renewable energy, fund renewable energy projects, and promote technology innovation through financial institutions to achieve sustainable development.

Keywords Renewable energy consumption · Non-renewable energy consumption · Financial development · Foreign direct investment · Institutional quality · Technological progress

Extended author information available on the last page of the article

Introduction

The sizes of the economies and populations of the world are anticipated to surge in the next couple of decades, whereby the energy demands can be assumed to rise in tandem. However, meeting the rising energy demand with the traditionally consumed unclean energy resources can impose adverse environmental consequences (Chishti et al., 2022; Jahanger et al., 2022a, 2022b; Murshed et al., 2022a, 2022b; Rehman et al., 2023). For instance, the total global CO_2 emissions between the years 2010 and 2019 have increased from 33.1 gigatons to 38 gigatons and were projected to increase in the coming years. Although CO_2 emissions are increasing globally, the countries that are emitting the highest amounts are not doing enough to reduce the emissions that contribute to global warming (Ganda, 2019; Ghazouani et al., 2020; Waheed et al., 2019). Global warming is a severe and difficult environmental challenge in this modern era. Carbon emissions from the burning of fossil fuels and greenhouse gas emissions are warming the climate throughout the world, according to scientists. Greenhouse gas emissions, particularly carbon dioxide emissions (CO_2 emissions), have contributed to global warming in recent decades, resulting in climate change (Farooq et al. 2022; Fatima et al., 2021; Ghazouani et al., 2020; Rafique et al., 2021; Fauzel & Seetanah, 2017; Shahzad et al., 2021; Shahzad, 2020). As a result, achieving environmental sustainability has become an important issue for our world. Most scholars have argued that improving energy efficiency rate, enhancing renewable production, technological advancement, and promoting green financial development inclusivity can help reduce carbon dioxide emissions (Khan et al., 2022; Murshed et al., 2022a, 2022b; Nathaniel et al., 2021a, 2021b; Rehman et al., 2023).

Environmental degradation is the deterioration of the environment through the depletion of resources. As a result of changes in economic performance, automation, population, and lifestyle around the world, environmental degradation has become a severe issue for both developed and developing countries. Environmental degradation has also become one of the major issues in the world that may have a negative impact on human health (Kanat et al., 2021; Khoshnava et al., 2020; Mujtaba & Shahzad, 2021; Udi et al., 2020; Wu et al., 2018), and countries long-term economic performance (Amin et al., 2020a, 2020b; Ding et al., 2020; Sharma et al., 2021). In view of this, the issue of environmental degradation has attracted massive attention from researchers and policymakers in this recent era (Destek & Sarkodie, 2019). It is widely recognized that environmental degradation, a contributor to global warming (Atasoy, 2017), arises from greenhouse gas (GHG) emissions (Amin et al., 2020a, 2020b). Several researchers have studied the impact of institutional value on an environmental eminence. According to several academics, strong ascendency and high-quality institutions are critical to enhanced environmental quality (Ibrahim & Law, 2016; Mavragani et al., 2016; Nasir et al., 2019). Numerous researchers in the past literature have studied the impact of technological innovation on carbon emissions. Excessive technological growth or advancement has been alleged to increase carbon emissions, resulting in a green paradox and harming economic development due to strong environmental rules in many countries (Dinda, 2018; Sun, 2016). However, a study by Xie et al. (2020) argues that there is a significant potential to minimize carbon emissions through technological advancement. Studies by Benedetti et al. (2020) and Jin et al. (2017) are in accordance with the study by Xie et al. (2020) that technological advancements minimize carbon emissions. Environmental deterioration is closely linked to globalization and foreign direct investment.

Globalization and environmental quality are two major challenges that shape the global economy. There are two main outcomes when it comes to globalization's consequences on environmental quality. Environmental quality is recognized to be deteriorated by globalization, according to one set of analysts, whereas the other group of analysts disagrees or argues otherwise.

The cause-and-effect relationship between globalization and environmental degradation is debatable. This link has yet to be demonstrated throughout Africa (Rafindadi, 2016). The size effect, the composition impact, and the method effect may all be used to scrutinize the upward or downward dynamics of globalization and the environment. Globalization tends to stimulate economic expansion and energy consumption, leading to an upsurge in environmental emissions due to the scale effect (Cole, 2004; Dedeoğlu and Kaya, 2013). In the composition effect, alternatively, economic activity rises as the fraction of carbon-intensive commodities in manufacturing processes decreases (Stern, 2007). Lastly, the technique effect transpires when globalization condenses energy consumption and pollutant emissions as a result of the spread of innovative technologies and technical expertise, both of which can aid in economic growth (Antweiler et al., 2001; Dollar & Kraay, 2004; Ranjan, 2008).

According to Klein et al. (2001), foreign direct investment (FDI) can be defined as the net inflow of investments to a company that operates in a country different than that of the investor who invested for the purpose of gaining a prolonged interest in management. The effect of increased FDI inflows on energy consumption and, as a result, environmental deterioration has prompted renewed concern since the introduction of the environmental Kuznets curve (EKC) hypothesis (Rafindadi, 2016). There have also been strong claims that foreign investment policies in primarily resource-rich nations countries encourage extractive industries, which are typically linked to detrimental environmental repercussions (Azapagic, 2004). Thus, the importance of analyzing the influence of FDI on the environment has been acknowledged, and substantial research has been conducted in the literature, albeit with varied results. A study by Pao and Tsai (2011) states that FDI intensifies carbon emissions, while other studies argue that FDI decreases carbon emissions. Similarly, other studies show that the environmental impact of FDI differs between countries, regions, or areas.

Africa is the second largest continent on the planet, with a population of over 1.37 billion representing 17.20 percent of the world's population. The African economy is growing rapidly, and it is expected that the economic growth will continue with the same trend in the future. African's economy depends on agriculture. Agriculture is the dominant sector of the continent, but due to the rapid growth of industrial sectors in Africa, agricultural land is being cut. Africa is facing high energy demand for which traditional energy sources are used to meet

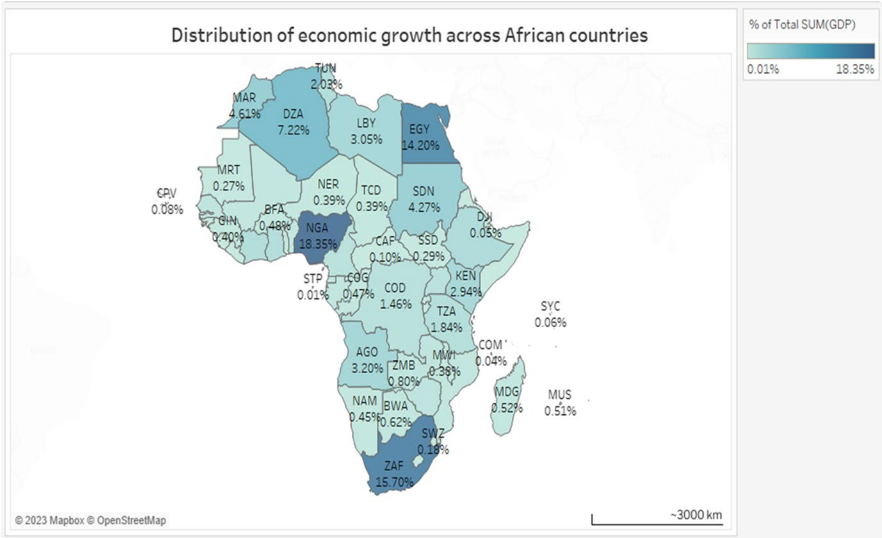

Fig. 1 Distribution of economic growth across African countries. Authors' own computation

its fast-increasing demand for energy (S. Nathaniel et al., 2021a, 2021b). Figure 1 depicts an Africa on the rise. Economic growth in regions, particularly the northern and southern regions where non-renewable demand is substantial (Fig. 2) and hence increased CO_2 emissions in those regions (Fig. 3). Figure 4 depicts regions

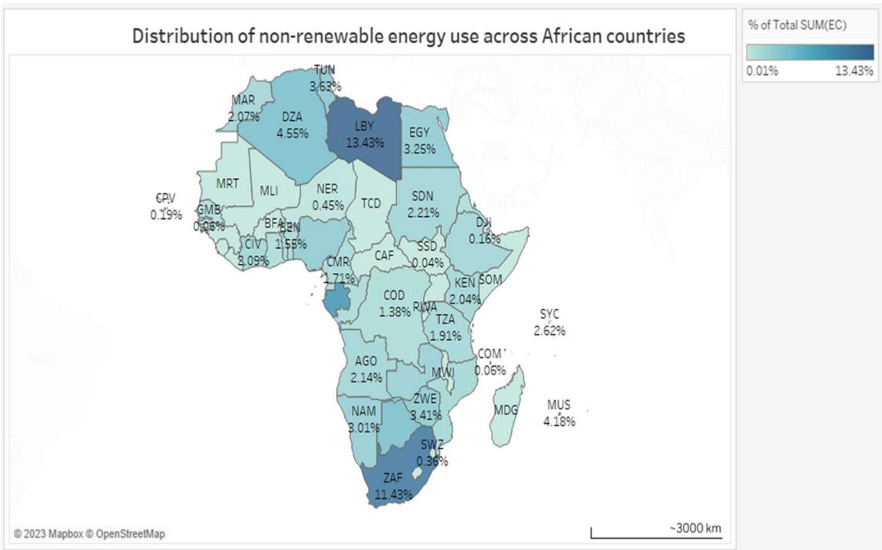

Fig. 2 Distribution of non-renewable energy use across African countries. Authors' own computation

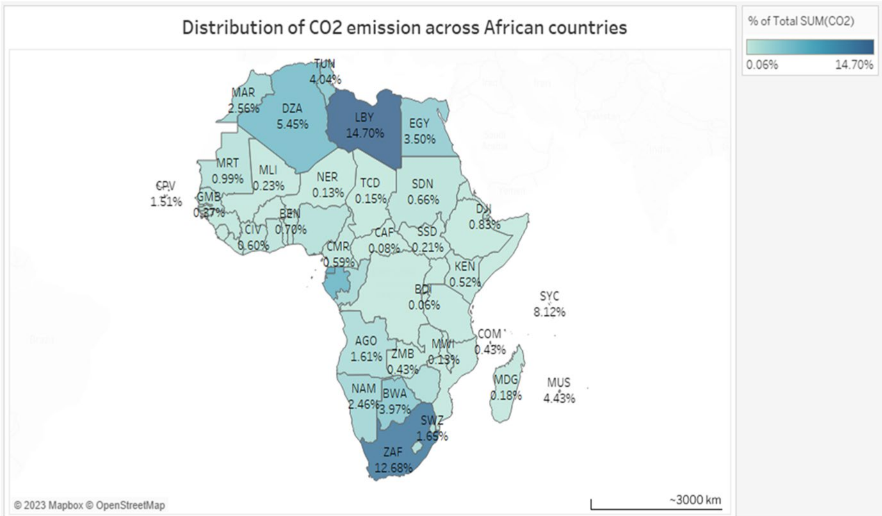

Fig. 3 Distribution of CO_2 emission across African countries. Authors' own computation

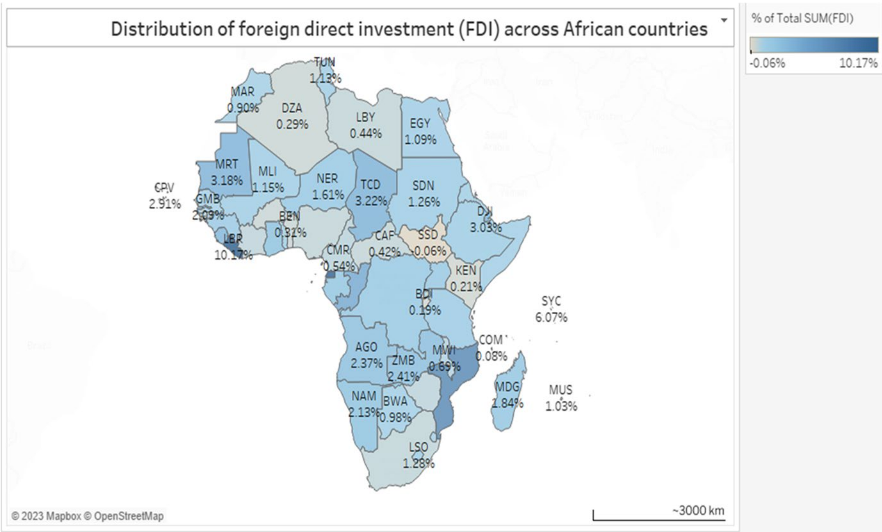

Fig. 4 Distribution of foreign direct investment (FDI) across African countries. Authors' own computation

with higher renewable energy use but lower growth, particularly in Sub-Saharan Africa. Because institutional quality to govern environmental quality is still relatively low, technological advancement is perceived to concentrate in the southern areas where economic growth is significant, and therefore, high environmental pollution is experienced (Fig. 5).

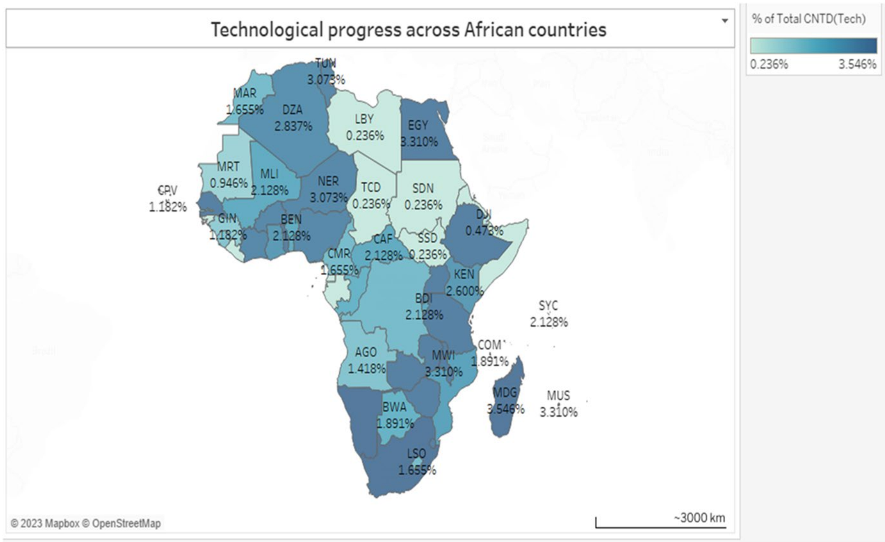

Fig. 5 Technological progress across African countries. Authors' own computation

Furthermore, most African countries continue to have very low institutional quality. The scatterplot in the appendix section reveals that the primary drivers of detrimental environmental quality in Africa include increased usage of non-renewable energy, low financial development, increased economic expansion, and poor institutional frameworks. Furthermore, increasing use of renewable energy, decreased use of non-renewable resources, technical advancement, and institutional quality are all elements that contribute to improved environmental quality.

Africa's energy sector predominantly relies on fossil fuels/non-renewable-energy consumption (S. Nathaniel et al., 2021a, 2021b). Consequently, such fossil fuel dependency within the nation's power sector has aggravated the poor environmental quality in Africa by amplifying the nation's energy production-based carbon emission levels. However, keeping into consideration the international commitments pledged by Africa under the Paris Accord and the Sustainable Development Goals (SDGs) agenda, it is pertinent for this African country to curb its energy production-based emission of greenhouse gases, especially carbon dioxide. Therefore, African countries have attached more importance to energy security, prioritizing low-carbon sources that have necessitated the consumption of renewable energy resources to achieve a resilient low-carbon system. In response to the above, this study investigates the impact of renewable energy consumption, non-renewable energy consumption, financial development, and foreign direct investment on environmental quality by considering the contribution of institutional quality and technological progress in Africa (Fig. 6). It is pertinent for African countries to boost renewable energy use to reduce fossil fuel dependency in most African nations to mitigate CO_2 emissions and ensure complementarity between economic growth and environmental development.

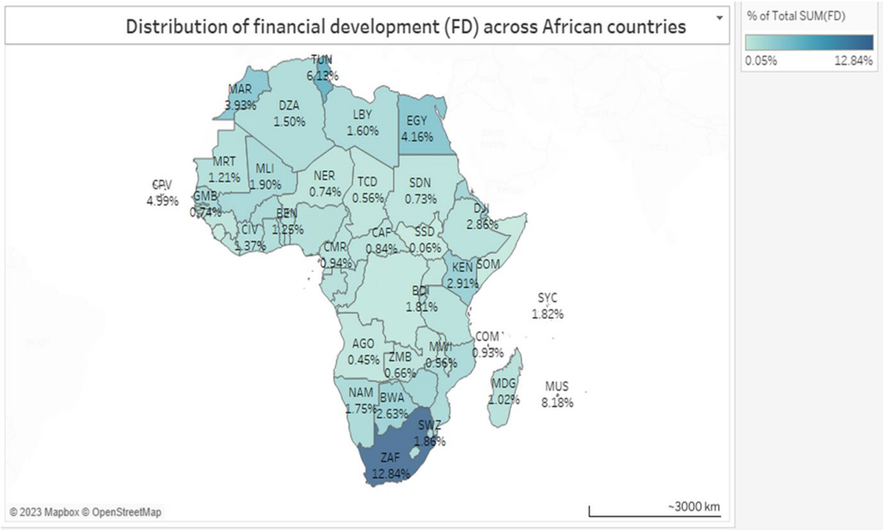

Fig. 6 Distribution of financial development across African countries. Authors' own computation

Today's global trend reveals an enormous increase in CO_2 emissions. The emission level increases in conjunction with many development factors, such as non-renewable energy use, financial development, and FDI. A research investigation on the impact of renewable energy consumption, non-renewable energy consumption, institutional quality, and financial development on environmental quality has become critical in recent years due to the SDGs' main goal of green technology and sustainability. Though much research has been done in these areas, very few studies have looked at the influence of development variables that raise CO_2 emissions, particularly in African countries. As a result, African countries became the focal study areas for this work. Panel data between 1996 and 2020 and panel estimation models are used for the study's analysis. This study makes a novel attempt to assess the effects of these development factors on CO_2 emissions (i.e., renewable energy consumption, non-renewable energy consumption, FDI, and financial development) while also taking into account the importance of institutional quality and technological advancement in promoting sustainable development by reducing environmental pollution in African countries (Fig. 7). The first model examined the influence of renewable energy consumption, non-renewable energy consumption, financial development, and foreign direct investment on environmental quality (CO_2 emission). The second model incorporated the influence of the factors above as well as institutional quality on CO_2 emissions. The third model studied the influence of CO_2 emissions on technology development, renewable energy consumption, non-renewable energy consumption, financial development, and FDI.

The rest of the paper is arranged as follows: the "Literature Review" section examines the literature on the topic, concentrating on the link between institutional quality, foreign direct investment, technological progress, energy consumption, financial development, environmental degradation, and pollutant emissions. The

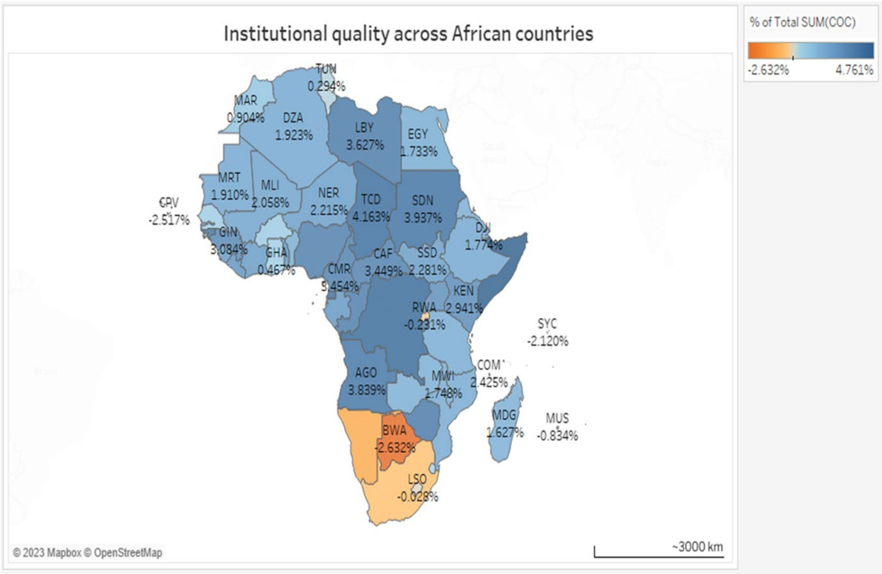

Fig. 7 Institutional quality across African countries. Authors' own computation

study factors and methods are discussed in the "Methodology" section, the results and discussions are shown in the "Results and Discussion" section, and the conclusion and recommendation of the findings are presented in the "Conclusion and Policy Recommendations" section.

Literature Review

The link between institutional quality, foreign direct investment, technological progress, energy consumption, financial development, and pollutant emissions is examined in this article. The literature review is divided into four sections for coherence. The four parts are the institutional quality-environment nexus, the technological progress-environment nexus, the energy consumption-carbon emission- financial development nexus, and the link amid financial development, energy consumption, and carbon emissions. Based on current and pertinent evidence, this study will discuss each nexus in detail**.**

Institutional Quality and Environment

In institutional theories, institutions have been discovered to be crucial to environmental quality. The influence of institutional excellence on environmental quality has piqued the curiosity of researchers. In studying the relationship between pollution and economic growth, several researchers have examined the influence of institutional quality. According to this group of researchers, economic and or institutional issues such as the rule of law, administrative brilliance, mismanagement, the threat of confiscation, and government contract refutation may impact the relationship between pollution and economic growth. A recent theory asserts that developed and developing nations' economic performance is mostly determined by their regulatory frameworks or absorptive capacity; this result has been extensively researched in the institution-growth literature. Majority of studies have found that strong governance and quality entities are environmentally beneficial, such as a study by Ali et al. (2019), which looked at the influence of quality institutions on CO_2 emissions in developing nations. The researchers used GMM estimators to analyze data from 47 countries. Their findings show that, in the sample nations, institutional quality reduces carbon emissions, reducing environmental deterioration, implying that quality institutions are crucial for improving environmental quality.

Alternatively, after studying 61 nations, Akhbari and Nejati (2019) discovered a confounding influence of institutional quality indicators on corruption. The study found that an improvement in corruption control had no significant impact on both industrialized and emerging economies. The necessity of environmental legislation for air pollution management has been underlined (He et al., 2007). The efficiency of political institutions is influenced by a good governance system concerned with environmental quality. The primary distorting mechanisms undermining environmental governance appear to be administrative inadequacy and inadequate institutional and financial institutional and financial embezzlement (Ward, 2008; Welsch, 2004). Controlling abatement costs is a key mechanism via which political institutions influence environmental quality.

Similarly, the influence of institutional quality on the environment and energy consumption in evolving nations was investigated by Azam et al. (2021), for the period 1991 to 2017; they used data from 66 developing countries. They utilized an institutional quality index and a system GMM model to find that institutional quality has a favorable influence on environmental indicators and a significant influence on energy consumption. Their findings demonstrate that, in poor nations, economic globalization has not improved ecological value eventually. Hamid et al. (2022a, 2022b) study aims to explore the effects of foreign direct investments, governance, democracy, renewable energy use, and economic growth on carbon dioxide emissions in the context of the BRICS countries over the period from 2006 to 2017. The associated findings reveal cointegrating associations between the study variables. Besides, the regression outcomes reveal that good governance (achieved by controlling corruption) and strong democracy (achieved by ensuring greater freedom for journalists) help to reduce carbon dioxide emissions in the long run. More importantly, the results also confirm that both good governance and stronger democracy further reduce carbon dioxide emissions by mediating between emission-inhibiting effects of foreign direct investment inflows in the BRICS countries.

In addition, good governance and stronger democracy exert moderating effects to reduce the emission-stimulating impacts associated with higher economic growth. Lastly, it is also witnessed that forgoing non-renewable energy use and adopting renewable energy instead help to curb the carbon dioxide emission levels further. Accordingly, considering these key findings, it is recommended that different countries should enhance the quality of governance and democracy, attract clean foreign direct investments, promote renewable energy use, and adopt clean economic growth strategies to decarbonize their respective economy.

Jahanger et al., (2022a, 2022b) study investigates the influence of democracy, autocracy, and globalization on carbon dioxide (CO_2) emissions in 69 developing countries from 1990 to 2018. They used the unit root approaches to scrutinize the level of stationarity and recognize that all concern variables were unified at first difference. Pedroni and the Kao cointegration methodologies were employed for the detection of long-run cointegration, and the conclusions discovered the presence of long-run relationships among variables. Furthermore, the study applied a fully modified ordinary least square (FMOLS) approach to estimate the long-run elasticity/coefficients. The outcomes showed that democracy and renewable energy significantly overcome the pressure on the environment. However, financial development and globalization significantly increase environmental damage.

Zakaria and Bibi (2019) study investigates the effect of financial development and institutional quality on the environment in South Asia. Other determinants of environmental quality included economic growth, energy consumption, FDI, trade openness, and institutional quality. For empirical analysis, panel data is used for the period 1984 to 2015. The estimated results indicate that institutional quality has a significant negative effect on carbon emissions. It also has significant negative moderating effects on carbon emissions. The findings show that 1% improvement in institutional quality will decrease pollution by 0.114%. The study suggests that South Asian countries should focus more on technology effect and not on scale effect of financial development.

Mehmood (2021) study also shows that institutional quality can play an important role to achieve cleaner production.

There is no unanimity in this past research, which is a significant drawback. There is a debate over the influence of political systems on carbon emissions. None of these studies has specifically examined the influence of political institutions on air pollutants, such as carbon, CH4, and organic water pollutants, in poor nations. Institutional quality identifies procedures for enforcing improved environmental rules to protect forests. Another study by Lau et al. (2014) examined the relationship between institutional quality, economic development, and carbon emissions in Malaysia from 1984 to 2008. In 2014, a study by Lau et al. discovered a long-term relationship between the research variables and also discovered a strong link between the quality of an institution and carbon emissions. Similarly, Ibrahim and Law (2016) claim that trade openness harms the environment in impoverished countries' institutional quality but is advantageous in countries with relatively high macroeconomic stability. Furthermore, Dasgupta and De Cian (2017) performed conceptual research on the influence of governance and quality institutions on the environment to conduct a theoretical study on the environment and environmental quality. The research also discovered that prior literature on environmental performance is more comprehensive than research on environmental policies and that there are conflicting findings on the effect of institutional quality on policy and environmental performance. However, most studies on the impact of institutional quality on environmental performance have found a significant correlation.

Environmental Development and Technological Advancement

The rate of technological advancement can be considered a significant determinant of CO_2 emissions. Carbon emissions, according to academics, are exterior manifestations of production and consumption processes that necessitate additional controls, such as environmental legislation. However, because every sword has two sides, technological advancement will have a "rebound effect," which might lead to an upsurge in CO_2 emissions as a result of rapid economic expansion (Bentzen, 2004). Imperfect environmental control policies, such as a severe carbon price, policy implementation delays, and subsidies for alternative energy sources, would incentivize resource owners to raise present extraction levels, resulting in a "green paradox," in which emissions grow rather than decline (Van Der Werf & Di Maria, 2012). Using VAR and VECM, Wang et al. (2011) investigated the technology-CO_2 nexus. Wang et al. (2011) discovered that increasing the number of technological patents might assist in reducing CO_2 emissions in the long term.

In 2003, a study by Soytas and Sari (2003) re-examined the causal link between GDP and energy consumption in 16 nations using the VEC model and discovered that energy conservation might damage economic growth in the long term. Liang and Wei (2012) developed a recursive dynamic CGE model to predict how lowering CO_2 levels through a carbon price will affect China's social economy. The effect of new energy technologies in decreasing emissions in Canada was investigated by Jordaan et al. (2017). Their findings suggest that investments in investigation and development connected to fossil fuels are strongly favored. They claim that funding for sustainable energy projects is available, but there is no database for investors to search for prospects. Clean energy innovation has been proposed to reduce emissions in Canada. For the period 1995 to 2010, Benedetti et al. (2020) utilized the spatial panel data technique to investigate the influence of revolutions on the atmosphere in 103 Italian regions. They discovered that the development of indigenous technologies had a favorable influence on emissions.

Jin et al. (2017) also investigated the influence of technological advancement on carbon emissions in China's energy industry from 1995 to 2012 and discovered an inverted U-curve affiliation between wealth and carbon emissions, as well as legislation stating that technical development in China lowers carbon emissions also indicating that, improving energy efficiency is also important which is good for lowering carbon emissions. Khan et al., (2020a, 2020b) study investigated the impact of technological progress on CO_2 emissions. They utilized the quantile regression method and balanced national data from Pakistan covering the period of 1991–2017 to establish relationships among the variables. The results and analysis reveal that technological progress has a negative impact on CO_2 emissions. Godil et al. (2021) examine the role of economic growth, technological innovation, and renewable energy in reducing transport sector CO_2 emissions in China by using the annual data of 1990–2018 by applying the QARDL approach. The findings disclosed that technological innovation significantly influences CO_2 emissions in China's transportation sector. Technological innovation showed a negative impact on CO_2 emissions related to transport.

Abid et al. (2022) studied the impact of financial development and technological innovation in the backdrop of the environment in the G8 countries (UK, USA, Canada, Germany, France, Italy Russia, and Japan), based on data from 1990 to 2019. According to the FMLOS estimator, a statistically significant long-run and negative association with CO_2 has been found between foreign direct investment, financial development, and technological innovation in G8 countries. Quality technological innovation is necessary for G8 countries. The study by Qayyum et al. (2021) explores the interaction between financial development, renewable energy consumption, technological innovations, and CO_2 emissions in India from 1980 to 2019, taking into account the critical role of economic progress and urbanization. The Autoregressive Distributed Lag (ARDL) model was used to quantify long-run dynamics, while the Vector Error Correction Model was used to identify causal direction (VECM). According to the study's conclusions, technical innovations was strongly negative in both the short and long run, indicating that increasing these measures will reduce CO_2 emissions. (Bilal et al., 2022) study explores the connection between technological innovation, globalization, and CO_2 emissions by controlling the critical influence of information and communication technology (ICT) and economic growth in a panel of One Belt One Road (OBOR) countries from 1991 to 2019, utilizing advanced and robust econometric strategies (second generation). The outcomes revealed that the linkage between technological innovation and CO_2 emissions is negative, and statically significant in all the regions (e.g., OBOR, South Asia, East and Southeast Asia, MENA, Europe, and Central Asia). Jebli and Hakimi (2023) study outcomes also show that technological advancement contribute to decreasing CO_2 emissions. Furthermore, in the long term, China's openness to trade, technical revolution, economic growth, and carbon emissions are all strongly and favorably related. A study by Fan et al. (2018) also discovered that trade and carbon emissions have a beneficial influence on growth in the long run, but carbon emissions have a detrimental effect on growth in the short term, while technological advancement is not important in the long term.

Environmental Deterioration, Foreign Direct Investment, and Financial Integration

Several scholars have looked at the impact of foreign direct investment on environmental quality in the past. FDI has long been seen to be an efficient way for rich nations to transfer sophisticated technology to poor nations (Herrerias et al., 2013). FDI has the potential to generate positive externalities (Shahbaz et al., 2013) and boost local technical levels, enhance production efficiency, and, therefore, augment local environmental quality through technological innovations transfer, knowledge spillovers, the introduction of executive skills, and the gains in productivity (Perkins & Neumayer, 2008). Despite the well-known economic advantages of foreign direct investment to host nations, there are drawbacks. Foreign direct investment, particularly dirty foreign direct investment, can potentially harm the environment and diminish the host country's natural resources. The environmental impact of FDI has also been investigated in terms of institutional quality, as these entities create standards and restrictions for foreign investors, which can assist in limiting FDI and its detrimental impact on environmental quality. According to Lan et al. (2012), technical transfer via FDI inflows is reliant on the absorptive capacity of the FDI host nations, which influences the role of FDI on pollution.

Hamid et al., (2022a, 2022b) studied the symmetric and asymmetric effects of foreign direct investments, economic growth, and capital investments on carbon dioxide emissions in Oman during 1980–2019. Using relevant econometric estimation methods for controlling structural break concerns in the data, the findings reveal evidence of asymmetric environmental impacts associated with shocks to the nation's foreign direct investment inflow, economic growth, and capital investment figures. Specifically, it is witnessed that positive shocks to the levels of foreign direct investment inflows, economic growth, and capital investments boost carbon dioxide emissions both in the short and long run. On the other hand, negative shocks to the levels of foreign direct investment inflows and economic growth are witnessed to reduce emissions. Besides, the findings also validate Oman's environmental Kuznets curve and pollution haven hypotheses. Hence, considering these key findings, the study recommends that countries should ideally pursue green economic growth policies by restricting inflows of unclean foreign direct investments and greening their financial sector to minimize their carbon dioxide emission figures collectively. Bakhsh et al. (2021) examine the moderating role of institutional quality and technological innovation on the empirical relationship between FDI inflows and four indicator variables of CO_2 emissions in 40 Asian countries from 1996 to 2016 using the generalized method of moment (GMM) estimation. The results showed that FDI inflows have positive impacts on CO_2 emissions; overall, from their empirical results, they concluded that the moderating role of institutional quality and technological innovation is crucial in the nexus between FDI and carbon CO_2 emissions and the interaction between institutional quality indicators and FDI inflows significantly reduce the level of CO_2 emissions. Furthermore, the significant moderating effect of technological innovation is observed on the association between FDI and CO_2 emissions. The results were important for policy makers in setting up long- and short-term policy to protect environmental quality. Shahbaz et al. (2019) examined the association between foreign direct investment (FDI) and carbon emissions for the Middle East and North African (MENA) region in 1990–2015, including biomass energy consumption as an additional determinant of carbon emissions. They applied the generalized method of moments (GMM) to validate the existence of the pollution haven hypothesis (PHH). The N-shaped association is also validated between FDI and carbon emissions. The causality analysis reveals that FDI causes CO_2 emissions. The empirical findings suggested policymakers to design comprehensive trade and energy policies by targeting the cleaner production practices, for not only to ensure environmental sustainability but also to fulfill the objectives of Sustainable Development Goals.

Wang et al. (2023) study showed that renewable energy and technological innovation both mitigate the level of environmental degradation while financial development, non-renewable energy use, and FDI contribute to the increase of environmental degradation in the long-run. Lan et al. (2012) discovered a link between FDI and environmental emissions in Chinese areas with lower levels of human resources. In a sample of 19 emerging Asian nations from 2002 to 2015, air pollution was measured by the quality of institutions. It was discovered that FDI inflows raise pollution at first but that improvements in institutional quality reduce this impact until a threshold of institutional quality is reached; nevertheless, after the barrier is reached, foreign direct investment has been shown to alleviate air pollution in Asian emerging countries (Huynh & Hoang, 2019). Deng et al. (2022) studied the impacts of social globalization, foreign direct investment inflows, and financial development on environmental pollution. Concerning foreign direct investment inflows, the study found that in the entire panel and the upper-middle-income and low-income sub-panels, foreign direct investment reduces and increases air pollution before and after the threshold level. In lower-middle-income countries, foreign direct investment inflows caused increased environmental pollution before and after the threshold. These findings imposed key policy implications concerning the attainment of the environment-related Sustainable Development Goals declared by the United Nations.

To explore whether foreign funds cause environmental deterioration in China, Jiang et al. (2017) used an urban data set of 150 Chinese cities from 2014 and spatial econometric models to account for spatial spillovers. It was found that foreign direct investment has a detrimental impact on China's air pollution and substantial geographical technical spillovers, resulting in improved air quality. For the period 1996 to 2012, Jan et al. (2019) considered the influence of governance on FDI influx in Pakistan. The study utilized many regression models and found that the overall model is significant and that strong governance substantially influences FDI influx. They demonstrate that improving governance metrics leads to an increase in FDI inflow.

However, it is possible to get contradictory results. It was discovered that it had two distinct effects: one was to wreak havoc on the environment by exporting polluting goods, and the other goal was to limit emission increase, which was boosted by trade openness. China, on the other hand, benefited from the overall effect. Pazienza (2015) found that FDI has an adverse effect on CO_2 emissions at the sectoral level (fishing and agriculture) in OECD nations. In contrast, apart from Europe and North Asia, Omri et al. (2015) emphasize a feedback effect amid FDI and CO_2 emissions in a thorough analysis using data from 54 countries. Their findings suggest that regional and country-level heterogeneities should be considered when examining the connection between FDI and emissions. Furthermore, Pao and Tsai (2011) examined the FDI- CO_2 connection in BRIC nations (Brazil, Russia, India, and China) using a panel cointegration approach. According to the causality results, the findings corroborate both the pollution haven and halo theories.

Carbon Emissions, Energy Use, and Financial Development

Financial growth has been a key factor in both the source and resolution of environmental issues caused by greenhouse gas emissions. Moreover, financial development encourages the formation of credit, investments, and economic expansion, all of which contribute to increasing energy consumption and, as a result, constitute environmental degradation (Zhang, 2011). On the other hand, financial development mitigates the negative effects of greenhouse gas emissions by providing sufficient funding for purchasing energy-intensive machinery and tools (Hogarth (n.d.); Charfeddine & Kahia, 2019). However, by strengthening corporate governance, financial development may also improve environmental quality (Claessens. (n.d.)). Environmental management practices are more likely to be followed by companies with good corporate governance. Frankel and Romer (1999) claimed in their landmark work that financial development may help to improve environmental conditions by encouraging multinational corporations to spend, which is typically associated with significant R&D effort. According to Jalil and Feridun (2011), financial development improves environmental quality in China. A study by Shahbaz et al. (2013) is in accordance with the conclusion made by Jalil and Feridun (2011). Al-mulali et al. (2015) showed that financial development in low-income, lower-middle-income, upper-middle-income, and high-income countries leads to improved environmental quality. Financial growth reduces environmental quality in 41 European Union and 58 Middle East and African (MEA) nations, according to Abid (2017). In Turkey, Ozturk and Acaravci (2013) looked at the causes of financial development, trade, economic growth, energy usage, and carbon emissions. Their findings indicated that per capital energy usage, real per capital income, the square of real per capital income, openness, and financial development, and per capital greenhouse gas emissions have a long-term causal link.

Al-mulali et al. (2015), however, conducted an empirical investigation of the relationship amid financial development and carbon dioxide emissions in European nations and concluded that financial growth degrades environmental quality by intensifying carbon dioxide emissions. Alam et al. (2022) study the impacts of energy consumption, energy efficiency, and financial development on Oman's prospects of attaining environmentally sustainable growth over the 1972–2019 period. The estimation strategy is designed to take into account the structural break issues in the data. Using the carbon productivity level as an indicator of environmentally sustainable economic growth, the study found long-run associations amid the study variables. Besides, higher energy consumption and greater financial development are found to impede carbon productivity, while improving energy efficiency is observed to boost carbon productivity in Oman. Therefore, it is pertinent for Oman to consume low-carbon and energy-efficient fossil fuels, improve energy efficiency levels, and green its financial sector to achieve environmentally sustainable growth. Shakib et al. (2022) study analysis showed that higher energy consumption, FDI inflows, and agricultural development cause environmental pollution by boosting CO_2 emissions. However, economic growth, technology development, financial progress, and renewable energy consumption are evidenced to exhibit bidirectional causal associations with CO_2 emissions. In line with these findings, several relevant policies can be recommended for the BRI to be environmentally sustainable. Deng et al. (2022) study examined the impacts of social globalization, foreign direct investment inflows, and financial development on environmental pollution in the context of a globally representative sample of 107 countries. Second-generation cointegration techniques and threshold regression estimators are used to examine the existence of long-term relationships and verify non-linear links between the variables of interest. Regarding financial development, we observe that before and after the threshold levels, financial development increases and decreases environmental pollution, respectively. Thus, these findings impose key policy implications concerning the attainment of the environment-related Sustainable Development Goals declared by the United Nations.

Kirikkaleli et al. (2022) investigated the effect of financial development and renewable energy consumption on consumption-based CO_2 emissions in Chile while controlling for economic growth and electricity consumption. The study outcomes clearly revealed that financial development and renewable energy consumption reduce the consumption-based CO_2 emissions in Chile. Sheraz et al. (2021) similarly showed that financial development and human capital decreased carbon emissions. Abbasi and Riaz (2016) also re-examined the relationship between financial development and carbon dioxide emissions by incorporating foreign direct investment in the emission equation. Salahuddin et al. (2015) used panel data from 1980 to 2012 to analyze the link between carbon dioxide emissions, economic growth, power consumption, and financial deepening in Gulf Cooperation Council (GCC) nations. Their findings showed that, in GCC nations, energy consumption and economic expansion boost CO_2 emissions, whereas financial development decreases them. As indices of financial development, their study looked at total debt, private sector credit, and market capitalization. Their findings showed an adverse affiliation between total credit and CO_2 emissions. Furthermore, Shahbaz et al. (2016) examined the uneven impact of financial growth on environmental quality in Pakistan from 1985 to 2014 quarterly. They concluded that financial development based on banks is environmentally harmful. In the same way, Khan et al., (2020a, 2020b) looked at the quality of institutions and the growth of financial markets in growing economies. For the investigation, they used static and dynamic models to analyze panel data for 189 nations. Their findings showed that high-quality financial institutions are critical for economic development. According to Zaidi et al. (2019), financial growth in Asia Pacific Economic Cooperation (APEC) nations lowers environmental deterioration. Based on statistics from 30 Chinese states. Xuezhou et al. (2022) looked at the complex relationships between financial development (FD) and environmental quality in Sub-Saharan African region, from 1980 to 2017. The study result showed that (i) financial development had a negative impact on CO_2 in four geographical regions (Western, Southern, Northern, and Central). As a result, FD in these countries minimizes carbon emissions and enhances the atmosphere. (ii) Also, FD had a positive impact on carbon emissions in Western Africa. As a result, FD in these countries increases CO_2 rather than improving environmental quality.

Zhao et al. (2021) concluded that financial depth enhances ecological quality, but financial performance degrades it. Financial growth in five ASEAN nations results in worse environmental quality, according to Nasir et al. (2019). Only a few studies on Sub-Saharan Africa have been done, and the results are mixed. According to Adams and Klobodu (2018), financial development has little effect on environmental quality. A study by Acheampong (2019) showed that financial growth has a mixed influence on environmental sustainability. Further studies by Acheampong et al. (2019) claimed that financial development degrades environmental quality, which is corroborated by Avom et al. (2020).

Renewable Energy Use and Carbon Emissions

Several scholars have investigated the effect of renewable energy use as it is the ultimate solution to the use of non-renewable energy use for sustainable economic growth. Much research has concluded that sustainability can be achieved by considering using renewable energy. For instance, Murshed et al. (2021) evaluated the validity of the environmental Kuznets curve (EKC) hypothesis using carbon and total ecological footprints to quantify environmental quality in the context of five South Asian economies: Bangladesh, India, Pakistan, Sri Lanka, and Nepal. Moreover, the EKC analysis precisely focused on the role of promoting greater utilization of renewable energy for mitigating the environmental adversities in South Asia. Using annual data from 1995 to 2015 and controlling for cross-sectional dependency and slope heterogeneity issues, their results confirmed the validity of the EKC hypothesis for the panel of the South Asian nations. Besides, enhancing the levels of renewable energy consumption and renewable electricity outputs was found to be pertinent in diminishing the carbon and ecological footprints. Moreover, the country-specific analysis led to statistical validation of the EKC hypothesis for Bangladesh, India, Nepal, and Sri Lanka but not for Pakistan. However, enhancing the overall use of renewable energy was unanimously associated with environmental betterment in all five South Asian nations. Hence, the results implicate that economic growth is both the short-run cause and the long-run solution to the environmental adversities within South Asia. Besides, augmenting renewable energy into the national energy-mixes is ideal for safeguarding environmental well-being in South Asia.

Another study by Murshed et al., (2022a, 2022b) evaluated the impacts of renewable electricity output, trade globalization, economic growth, financial development, urbanization, and technological innovation on sectoral carbon dioxide emissions in Argentina during the 1971–2014 period. Overall, the findings suggest that enhancing renewable electricity output share in the nation's total electricity output figure helps curb carbon dioxide emissions generated from Argentina's energy, manufacturing and industry, residential and commercial buildings, and transportation sectors. In addition, financial development and urbanization are also evidenced to exert carbon dioxide emission-stimulating impacts, while technological innovation is witnessed to be necessary for curbing sector-based carbon dioxide emissions in Argentina. Accordingly, to decarbonize the economy, this study recommends the government of Argentina adopt necessary policies for fostering renewable energy transition within the electricity sector, greening the trade globalization strategies, achieving environmentally sustainable economic growth, developing the financial sector by introducing green financial schemes, planning sustainable urbanization, and financing technological development-oriented projects. Hamid et al., (2022a, 2022b) revealed that forgoing non-renewable energy use and adopting renewable energy instead help to curb carbon dioxide emission levels further. Accordingly, considering these key findings, it is recommended that different countries promote renewable energy use and adopt clean economic growth strategies to decarbonize their respective economies. Alam et al. (2022) study showed that improving energy efficiency is observed to boost carbon productivity in Oman. Therefore, it is pertinent for

Oman to consume low-carbon and energy-efficient fossil fuels, improve energy efficiency levels, and green its financial sector to achieve environmentally sustainable growth. Shakib et al. (2022) observed that exploiting renewable energy sources, which are relatively cleaner compared to the traditionally consumed fossil fuels, and fostering agricultural sector development can significantly improve environmental well-being by curbing the emission levels further. employed advanced panel data econometric techniques that account for cross-sectional dependence and slope heterogeneity issues to explore the impacts of nuclear and renewable energy use regarding CO_2 emission mitigation in six of the seven G7 countries. The core objective of this study is to justify whether energy diversification through the promotion of nuclear and renewable energy consumption can assist the G7 nations in complying with their commitments concerning the Paris Climate Change and Sustainable Development Goals agendas. The country-specific results suggested that nuclear energy significantly reduces CO_2 emissions in all countries except Canada and the USA. Also, renewable energy significantly curbs CO_2 emissions only in Canada and France. In line with these findings, it is pertinent for the G7 countries to boost nuclear energy use to reduce the majority of the G7 nations' fossil fuel dependency and mitigate CO_2 emissions. Moreover, it is also suggested that these nations adopt relevant policies to further green their consumption and production processes to ensure complementarity between economic growth and environmental development.

Murshed et al., (2022a, 2022b) examined the impacts of renewable electricity generation, economic globalization, economic growth, and urbanization on carbon dioxide emissions generated from electricity and heat production in Argentina. Using annual frequency data from 1971 to 2016, recent econometric methods were applied to control for multiple structural breaks in the data. The major findings from the econometric analyses affirmed long-run associations between renewable electricity generation, economic globalization, economic growth, urbanization, and energy production-based carbon dioxide emissions in Argentina. Enhancing renewable electricity output shares is found to curb these emissions while economic globalization and urbanization are witnessed to boost them. Moreover, renewable electricity generation and economic globalization were found to reduce energy production-related carbon dioxide emissions in Argentina jointly. Khan et al. (2022) examined whether improving energy efficiency rate, enhancing renewable electricity production, and promoting financial inclusivity can help the Next Eleven countries reduce their carbon dioxide emissions. Overall, the findings revealed that energy efficiency improvement and greater renewable electricity shares in total electricity outputs mitigate carbon dioxide emissions in the long run. Contrarily, financial inclusion, economic growth, and international trade are observed to boost carbon dioxide emissions. Moreover, energy efficiency and financial inclusion were found to jointly inhibit emissions, whereby the mediating and moderating effects of energy efficiency on the financial inclusion-carbon dioxide emissions nexus are verified. Furthermore, these findings were robust across alternate estimation techniques and when total greenhouse gas emissions are considered an alternative proxy for measuring environmental well-being. Accordingly, several relevant environmental sustainability-related policies were recommended to the concerned governments.

Economic Growth, Energy Consumption, and CO_2 Emissions

Previous existing literature has proved the existence of the EKC hypothesis. Considering globalization effects, many scholars have been interested in studying the EKC hypothesis for the past few years. For instance, Ozturk et al. (2022) investigated the nexus between CO_2 emissions, economic growth, energy consumption, and pilgrimage tourism in Saudi Arabia from 1968 to 2017. The dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS) methods were employed in this study. FMOLS results proved that energy consumption, number of pilgrims, and oil prices positively affect CO_2 emissions, and GDP negatively affects it. Also, the DOLS results implied that only energy consumption has a positive effect on carbon emissions. In addition, there was unidirectional causality from CO_2 to pilgrimage tourism and from pilgrimage tourism to oil, and there was bidirectional causality between pilgrimage tourism and GDP. Therefore, the environmental cost of pilgrimage tourism was inevitable.

Hamid and et al., (2022a, 2022b) examined the symmetric and asymmetric effects of foreign direct investments, economic growth, and capital investments on carbon dioxide emissions in Oman during 1980–2019. Using relevant econometric estimation methods for controlling structural break concerns in the data, the findings reveal evidence of asymmetric environmental impacts associated with shocks to the nation's foreign direct investment inflow, economic growth, and capital investment figures. Specifically, it is witnessed that positive shocks to the levels of foreign direct investment inflows, economic growth, and capital investments boost carbon dioxide emissions both in the short and long run. On the other hand, negative shocks to the levels of foreign direct investment inflows and economic growth are witnessed to reduce emissions. Besides, the findings also validated the environmental Kuznets curve and pollution haven hypotheses in the context of Oman. Hence, considering these key findings, the study recommended that countries should ideally pursue green economic growth policies by restricting inflows of unclean foreign direct investments and greening their financial sector in order to minimize their carbon dioxide emission figures collectively. Farooq et al. (2022) analytically explored and empirically tested the links of globalization with environmental quality. For empirical analysis, a large panel of data 180 countries was assembled over the period 1980–2016. The empirical results showed that globalization helps to ameliorate environmental degradation. Panel quantile regression results also supported the favorable role of globalization, mainly for economies with existing low levels of carbon emissions. However, the decomposition of globalization into different domains revealed that this finding cannot be generalized for all dimensions of globalization. In particular, this study found robust evidence that economic globalization harms environmental sustainability. However, political globalization has been shown as a tool for enhancing environmental quality. Finally, the environmental Kuznets curve was validated in all models. These findings remain consistent with different robustness checks. (FDI, government).

Additionally, Shakib et al. (2022) investigated the dynamics of energy, economy, and environment among 42 BRI developing countries using an annual frequency panel dataset from 1995 to 2019. The major findings from the econometric analyses revealed that higher energy consumption levels, economic growth, population growth rate, and FDI inflows exhibit adverse environmental consequences by boosting the CO_2 emission figures of the selected developing BRI member nations. However, it is interesting to observe that exploiting renewable energy sources, which are relatively cleaner compared to the traditionally consumed fossil fuels, and fostering agricultural sector development can significantly improve environmental well-being by curbing the emission levels further. On the other hand, financial development is found to be ineffective in explaining the variations in the CO_2 emission figures of the selected countries. Besides, the causality analysis shows that higher energy consumption, FDI inflows, and agricultural development cause environmental pollution by boosting CO_2 emissions. However, economic growth, technology development, financial progress, and renewable energy consumption are evidenced to exhibit bidirectional causal associations with CO_2 emissions. In line with these findings, several relevant policies can be recommended for the BRI to be environmentally sustainable. Rehman et al. (2022) study investigated the influence of carbon dioxide emission to population growth, food production, economic growth, livestock, and energy utilization in Pakistan. The STIRPAT (Stochastic Impact by Regression on Population, Affluence and Technology) model with the extension of an ARDL (Autoregressive Distributed Lag) method was utilized to demonstrate the linkage amid variables. Outcomes during short-run investigation revealed that variables population growth, economic growth, rural population growth, and livestock production uncovered a productive association with CO_2 emission. Furthermore, via long-run population growth, economic growth, rural population growth, livestock production, and energy utilization have positive interaction with CO_2 emission, while the variables food production and urban population growth demonstrated an adverse influence to CO_2 emission during long- and short-run interaction. Similarly, the error correction model exposed that population growth, economic progress, livestock and energy utilization have constructive interaction to CO_2 emission, while the variables food production and urban and rural population growth exposed an adverse impact to CO_2 emission.

Chishti et al. (2022) study developed the theoretical framework to illustrate the link between aggregate domestic consumption spending and carbon dioxide emissions and deploy Autoregressive Distributed Lag (ARDL), asymmetric ARDL, and the threshold non-linear ARDL (NARDL) techniques. The results of the ARDL method suggested that only in the short run does aggregate domestic consumption spending significantly affect carbon dioxide emissions. Furthermore, the findings of the NARDL approach revealed that the positive and negative shocks significantly deteriorate and ameliorate the environmental quality by increasing and decreasing the pollution in the short and long run. Even though the outcome of the threshold NARDL technique supports the results of the approaches, the novelty of the current study was to find out the threshold in aggregate domestic consumption spending, which carries a significant role in determining the carbon emissions in both periods. Besides, the study inferred that fossil fuel energy and trade openness also degrade the Pakistani climate by boosting atmospheric pollution. Additionally, the application of the asymmetric Granger causality test validated the results by asserting the casual relationship between aggregate domestic consumption spending and carbon dioxide emissions. Based on the results, it was suggested the authorities start promoting the public deployment of green products to obtain green and sustainable development.

The study by Murshed et al., (2022a, 2022b) examined the impacts of renewable electricity generation, economic globalization, economic growth, and urbanization on carbon dioxide emissions generated from electricity and heat production in Argentina. Using annual frequency data from 1971 to 2016, recent econometric methods were applied to control for multiple structural breaks in the data. The major findings from the econometric analysis also validated the authenticity of the environmental Kuznets curve (EKC) hypothesis. Finally, the causality analysis reveals evidence of unidirectional causalities running from renewable electricity generation, economic globalization, economic growth, and urbanization to energy production-related carbon dioxide emissions in Argentina. In line with these findings, this study recommends several viable policies that can be implemented to help Argentina control the growth of its energy production-based carbon dioxide emissions. Again, Murshed et al. (2021) paper scrutinized the validity of the greenhouse emissions-induced environmental Kuznets curve (EKC) hypothesis, controlling for liquefied petroleum gas (LPG) consumption, FDI inflows, and trade openness, in the context of six South Asian economies. Besides, the impacts of LPG use on both aggregate and disaggregated emissions of greenhouse gases were also evaluated. Using annual data from 1980 to 2016, the elasticity estimated from the Autoregressive Distributed Lag (ARDL) regression analysis confirms the authenticity of the EKC hypothesis for Bangladesh, India, Sri Lanka, and Bhutan. In the cases of Pakistan and Nepal, economic growth, in the long run, was evidenced by monotonically increasing and decreasing the greenhouse emissions, respectively. However, LPG consumption is found to homogenously reduce all types of greenhouse emissions in each of the selected South Asian nations. Moreover, in most cases, statistical evidence of joint favorable impacts of economic growth and LPG consumption on the environment are ascertained. Furthermore, the Hacker and Hatemi-J bootstrapped causality analysis finds causal relationships between economic growth, greenhouse emissions, and LPG consumption. However, the causality estimates are found to be heterogeneous across the different South Asian nations considered in the analysis. The results, in a nutshell, denote that economic growth is both the cause and the solution to the greenhouse emission problems faced by the South Asian economies. Moreover, the results also assert that LPG can be a transitional fuel to reduce these emissions before the South Asian nations are ready to undergo transition from non-renewable to renewable energy consumption. Hence, the findings impose key fuel-diversification policy implications for the South Asian governments.

Author(s)	Country	Sample period	Methodology	Main findings
Summary of the literature on the institutional quality and environment				
Ali et al. (2019)	47 countries	Obtained from two different sources	GMM estimators	Institutional quality reduces carbon emissions
Akhbari and Nejati (2019)	61 countries	2003–2016	Panel threshold model	Confounding influence of institutional quality indicators on corruption
Azam et al. (2021)	66 developing countries	1991–2017	System GMM model	Institutional quality has a favorable influence on environmental indicators
Hamid et al., (2022a, 2022b)	BRICS countries	2006–2017	Panel cointegration	Good governance (achieved by controlling corruption) and strong democracy (achieved by ensuring greater freedom for journalists) help to reduce carbon dioxide emissions
Lau et al. (2014)	Malaysia	1984–2008	Panel ARDL	Strong link between the quality of an institution and carbon emissions
Ibrahim and Law (2016)	40 SSA countries	1980–2003	System GMM	Institutional reforms are unequivocally environmental improving
Summary of the literature on the environmental development and technological advancement				
Benedetti et al. (2020)	103 Italian regions	1995–2010	Spatial panel data technique	Development of indigenous technologies had a favorable influence
Jin et al. (2017)	China	1995–2012	ARDL model	Technical development in China lowers carbon emissions
Khan et al., (2020a, 2020b)	Pakistan	1991–2017	Quantile regression method	Technological progress has a negative impact on CO_2 emissions
Godil et al. (2021)	China	1990–2018	QARDL approach	Technology innovation shows a negative impact on emissions of CO_2

Author(s)	Country	Sample period	Methodology	Main findings
Abid et al. (2022)	G8 Countries	1990–2019	FMLOS estimator	Negative association has been found between technological innovation and CO_2 emission
Qayyum et al. (2021)	India	1980–2019	ARDL and VECM model	Technical innovations was strongly negative in both the short and long run
Bilal et al. (2022)	One Belt One Road (OBOR) countries	1991–2019	Panel cointegration	Technological innovation and CO_2 emissions is negative and statically significant in all the regions (e.g., OBOR, South Asia, East and Southeast Asia, MENA, Europe, and Central Asia)
Jebli and Hakimi (2023)	Top 10 countries	2004–2019	PMG-ARDL	Technological advancement contributes to decreasing CO_2 emissions
Summary of the literature on the environmental deterioration, foreign direct investment, and financial integration				
Hamid et al., (2022a, 2022b)	Oman	1980–2019	Econometric method for controlling structural break	Foreign direct investment inflows boost carbon dioxide emissions both in the short and long run
Deng et al. (2022)	107 countries	1980–2018	Panel cointegration techniques	Foreign direct investment inflows cause increased environmental pollution
Jiang et al. (2017)	China	2014	Spatial econometric models	Foreign direct investment has a detrimental impact on China's air pollution
Huynh and Hoang (2019)	19 developing Asian countries	2002–2015	FGLS and system GMM	Foreign direct investment has been shown to alleviate air pollution
Pazienza (2015)	30 OECD countries	1981–2005	OLS, FE, RE panel model	An increase of FDI reduces the CO_2 level

Author(s)	Country	Sample period	Methodology	Main findings
Bakhsh et al. (2021)	40 Asian countries	1996–2016	Panel GMM	FDI inflows have positive impacts on CO_2 emissions
Shahbaz et al. (2019)	Middle East and North African (MENA) region	1990–2015	Panel GMM	FDI causes CO_2 emissions
Summary of the literature on the carbon emissions, energy use, and financial development				
Zhang (2011)	China	1980–2005	Panel cointegration technique	China's financial development acts as an important driver for carbon emission increase
Xuezhou et al. (2022)	SSA region	1980–2017	Panel VAR	Mixed results
Charfeddine and Kahia (2019)	MENA region	1980–2015	Panel VAR	Financial development has positive influence on CO_2 emissions
Al-mulali et al. (2015)	129 countries	1980–2011	Panel cointegration technique	Financial development can improve environmental quality in the short run and long run
Alam et al. (2022)	Oman	1972–2019	Panel VAR	Financial developments are found to impede carbon productivity
Shakib et al. (2022)	42 BRI developing countries	1995–2019	OLS (FMOLS) and the dynamic OLS (DOLS)	Financial progresses are evidenced to exhibit bidirectional causal associations with CO_2 emissions
Deng et al. (2022)	107 countries	1980–2018	Panel cointegration techniques	Mixed results
Nasreen et al. (2017)	South Asian countries	1980–2012	Panel cointegration techniques	Financial stability improves environmental quality
Khan et al., (2020a, 2020b)	Global panel	2002–2019	Two-step system GMM	Financial development lower environmental quality
Zaidi et al. (2019)	Asia Pacific Economic Cooperation countries	1990–2016	Panel cointegration techniques	Financial development significantly reduces carbon emissions
Zhao et al. (2021)	30 Chinese provinces	1999–2017	Spatial Durbin model	Financial development has direct and moderating effects on environmental pollution

Author(s)	Country	Sample period	Methodology	Main findings
Nasir et al. (2019)	5 ASEAN nations	1982–2014	Dynamic OLS (DOLS) and Fully Modified OLS (FMOLS)	Financial growth results in worse environmental quality
Adams and Klobodu (2018)	26 African countries	1985–2011	Chow test, cross-country regressions, and the Generalized Method of Moments (GMM	Financial development, is a significant determinant of environmental degradation
Acheampong et al. (2019)	46 SSA countries	2000–2015	System-GMM	Financial development contributes to the rise of CO_2 emissions
Summary of the literature on the renewable energy use and carbon emissions				
Murshed et al. (2021)	5 South Asian economies	1995–2015	Panel regression analysis	Renewable energy consumption was found to be pertinent in diminishing the carbon and ecological footprints
Murshed et al., (2022a, 2022b)	Argentina	1971–2014	Time series analysis	Enhancing renewable electricity helps to curb carbon dioxide emissions
Hamid et al., (2022a, 2022b)	Oman	1980–2019	Econometric method for controlling structural break	Adopting renewable energy help to curb the carbon dioxide emission levels
Alam et al. (2022)	Oman	1972–2019	Panel VAR	Improving energy efficiency is observed to boost carbon productivity
Shakib et al. (2022)	42 BRI developing countries	1995–2019	OLS, FMOLS, and the dynamic OLS (DOLS)	Exploiting renewable energy sources significantly improve environmental well-being by curbing the emission levels
Nathaniel et al., (2021a, 2021b)	G7 countries	1990–2017	Panel cointegration	renewable energy significantly curbs CO_2 emissions
Murshed et al., (2022a, 2022b)	Argentina	1971–2016	VAR model	Enhancing renewable electricity output shares is found to curb carbon emissions

Author(s)	Country	Sample period	Methodology	Main findings
Summary of the literature on the economic growth, energy consumption, and CO_2 emissions				
Ozturk et al. (2022)	Saudi Arabia	1968–2017	FMOLS and the dynamic OLS (DOLS)	Energy consumption, number of pilgrims and oil prices have a positive effect on CO_2 emissions and GDP has a negative effect
Farooq et al. (2022)	180 countries	1980–2016	Panel quantile regression	Economic globalization is harmful to environmental sustainability
Hamid et al., (2022a, 2022b)	Oman	1980–2019	VAR model	Foreign direct investment inflows, economic growth, and capital investments boost carbon dioxide emissions both in the short and long run
Shakib et al. (2022)	42 BRI developing countries	1995–2019	OLS, FMOLS, and the dynamic OLS (DOLS)	Energy consumption, economic growth, population growth rate, and FDI inflows exhibit adverse environmental consequences by boosting the CO_2 emission
Rehman et al. (2022)	Pakistan	1990–2017	STIRPAT (Stochastic Impact by Regression on Population, Affluence and Technology) model with the extension of an ARDL	Population growth, economic growth, rural population growth, livestock production, and energy utilization have positive interaction with CO_2 emission
Chishti et al. (2022)	Pakistan	1973–2018	ARDL, NARDL technique	Aggregate domestic consumption spending significantly affects carbon dioxide emissions
Nathaniel et al., (2021a, 2021b)	G7 countries	1990–2017	Panel cointegration	Economic growth is found to initially boost the CO_2 emission level

Author(s)	Country	Sample period	Methodology	Main findings
Murshed et al., (2022a, 2022b)	Argentina	1971–2016	Econometric method for controlling structural break	Results validate the authenticity of the environmental Kuznets curve (EKC) hypothesis
Murshed et al., (2021)	5 South Asian economies	1980–2016	ARDL model	Results validate the authenticity of the environmental Kuznets curve (EKC) hypothesis

Methodology

Empirical Model Specification and Variables

A study on the impact of renewable energy consumption, non-renewable energy consumption, institutional quality, and financial development on environmental quality has become fundamental in recent years due to the main goal of the Sustainability Development Goals (SDGs) towards green technology and sustainability. Though many pieces of literature have focused on these areas, few have been high-lighted towards developing countries such as Africa. Therefore our study has been developed towards African countries. The current study utilizes panel data for all the 54 African countries for the period 1996 to 2020. The study explored the data collected from the World Development Indicator of the World Bank. Our study uses three models, whereby the first model looked at the impact of renewable energy consumption, non-renewable energy consumption, financial development, and foreign direct investment on environmental quality (CO_2 emission). The second model exploited the impact of the above variables with the inclusion of institutional quality towards CO_2 emission. The third model augmented technology development with renewable energy consumption, non-renewable energy consumption, financial development, and FDI and investigated its impact on CO_2 emission. The three models are demonstrated in Eqs. (1), (2), and (3) as shown below.

$$\begin{aligned} CO_{2it} &= \beta_0 + \beta_1 CO_{2i,t-1} + \beta_2 REC_{i,t} + \beta_3 EC_{i,t} + \beta_4 FD_{i,t} \\ &\quad + \beta_5 FDI_{i,t} + \beta_6 GDP_{i,t} + \beta_7 POPG_{i,t} + \beta_8 INV_{i,t} + \beta_9 LF_{i,t} \end{aligned} \tag{1}$$

$$\begin{aligned} CO_{2it} &= \beta_0 + \beta_1 CO_{2i,t-1} + \beta_2 REC_{i,t} + \beta_3 EC_{i,t} + \beta_4 FD_{i,t} + \beta_5 FDI_{i,t} \\ &\quad + \beta_6 INSQ_{i,t} + \beta_7 GDP_{i,t} + \beta_8 POPG_{i,t} + \beta_9 INV_{i,t} + \beta_{10} LF_{i,t} \end{aligned} \tag{2}$$

$$\begin{aligned} CO_{2it} &= \beta_0 + \beta_1 CO_{2i,t-1} + \beta_2 REC_{i,t} + \beta_3 EC_{i,t} + \beta_4 FD_{i,t} + \beta_5 FDI_{i,t} \\ &\quad + \beta_6 TECH_{i,t} + \beta_7 GDP_{i,t} + \beta_8 POPG_{i,t} + \beta_9 INV_{i,t} + \beta_{10} LF_{i,t} \end{aligned} \tag{3}$$

The definitions of the above variables in the equations are as follows: CO_2 is a measure of carbon dioxide emission, and it is the main variable of interest. It is a proxy for environmental pollution. *REC* represents renewable energy consumption. It is expected to have an inverse relationship with environmental degradation since the use of renewable energy leads to a more sustainable environment. *EC* is a symbol of non-renewable energy consumption. *EC* acts as a stimulator to environmental degradation as it promotes the consumption of non-renewable energy thus leading to the emission of more CO_2 into the atmosphere. *FD* is a proxy of financial development, and *FD* is believed to have stringent environmental policies by only supporting businesses that promote green technologies thereby excluding business activities that may damage the environment. Therefore, *FD* is expected to reduce CO_2 emission hence improving environmental quality. *FDI* is a connotation of foreign direct investment. *FDI* may inhibit mixed results due to its Pollution Haven Hypothesis or Pollution Halo Hypothesis. The Pollution Haven Hypothesis states that the increase in *FDI* may promote environmental pollution as it believes that most industries that failed to meet the environmental standards set by the developed countries tend to flow towards developing countries such as African countries where the institutional policies quality is still weak towards environmental sustainability thereby increasing CO_2 emission. The Pollution Halo Hypothesis, on the other hand, states that FDI, through the transmission of its sophisticated technologies that aid in promoting renewable energy usage in developing countries, leads to promoting environmental sustainability by reducing CO_2 emission. *GDP*African countries' economic growth is measured in terms of GDP per capita. GDP is expected to increase emissions since growth requires energy consumption, which stimulates carbon dioxide emission, especially in developing countries where the EKC hypothesis is still not met. *POPG* refers to population growth, and various studies have confirmed that increased population growth increases the level of carbon dioxide emissions. *INV* refers to gross fixed capital formation and it's a proxy of investment. *LF* is the total labor force. *INSQ* refers to institutional quality, which comprises six variables as a proxy of the qualities of institutions in African countries; RL represents the rule of laws which the government institutions formulate, VA refers to people's voice and accountability, PS refers to political stability, GOVE is a proxy for government effectiveness, RQ refers to regulatory quality, and COC refers to control of corruption. Institutional quality indicators are collected from the World Governor Indicator (WGI) and they have a variation from − 2.5 to 2.5 where the lowest value represents poor institutions and good quality institutions are represented by the upper positive values. *TECH* is a proxy for technological progress. Technological progress is measured by total high technology products exports calculated as a percent of the total manufactured produced exports. Much literature has mentioned that technological progress is a compensating factor in carbon dioxide emission.

Table 1 presents countries' names; Table 2 presents variable definitions while Table 3 shows the descriptive statistics of the variables used in the study. The correlation matrix of the variables is reported in the Appendix.

Table 1 African countries

Nigeria	Kenya	Mozambique	Burkina Faso	Somalia
Ethiopia	Uganda	Ghana	Mali	Zimbabwe
Egypt	Algeria	Madagascar	Malawi	Guinea
DR Congo	Sudan	Cameroon	Zambia	Rwanda
Tanzania	Morocco	Côte d'Ivoire	Senegal	Benin
South Africa	Angola	Niger	Chad	Burundi
Liberia	Mauritania	Namibia	Botswana	Lesotho
Central African Republic	Eritrea	Gambia	Gabon	Guinea-Bissau
Eswatini	Djibouti	Comoros	Togo	Seychelles
Sao Tome and Principe	Tunisia	South Sudan	Congo	Sierra Leone
Equatorial Guinea	Libya	Mauritius	Cabo Verde	

Source: Authors' own computation

Table 2 Definitions of the variables

i	54 African countries
t	Years 1996–2020
CO_2	Carbon dioxide emissions (metric tons per capita)
EC	Energy consumption (kg of oil equivalent per capita)
REC	Renewable energy consumption from renewable sources
FD	Financial development (credit to the private sector as a % of GDP)
FDI	Foreign direct investment inflow (% of GDP)
GDP	Real gross domestic product per capita (constant 2010 US$)
POPG	Population growth
INV	Gross fixed capital formation as a % of GDP
LF	Total labor force
TECH	Product of high – technology exports (% of total manufactured product export)
RL	Rule of law (values between – 2.5 and 2.5)
VA	Voice and accountability (values between – 2.5 and 2.5)
PS	Political stability (values between – 2.5 and 2.5)
GOVE	Government effectiveness (values between – 2.5 and 2.5)
RQ	Regulatory quality (values between – 2.5 and 2.5)
COC	Control of corruption (values between – 2.5 and 2.5)

Source: Authors' own computation

Econometric Models

Our study investigates the impact of renewable energy consumption, non-renewable energy consumption, financial development, and foreign direct investment on CO_2 emission by also considering the role of institutional quality and technological progress. The study employs the ordinary least square model (OLS) and the fixed effect model (FE) as the base model to confirm the preceding literature about the related

Table 3 Descriptive statistics

Variable	Obs	Mean	Std. Dev	Min	Max
CO_2	1334	−.914	1.463	−4.116	2.458
LEC	982	6.006	1.163	.086	8.686
REC	1334	3.77	1.181	−2.83	4.588
FD	1306	2.581	.904	−.931	4.666
FDI	1254	.831	1.423	−6.684	5.087
GDP	1301	7.191	1.037	5.234	9.93
POPG	1335	.762	.613	−6.079	2.094
INV	1265	2.968	.571	−1.228	4.968
LF	1325	14.9	1.5	10.587	17.962
TECH	845	1.243	2.081	−9.247	5.843
RL	1,176	−.702	.657	−2.606	1.077
VA	1339	2.351	.382	.693	2.396
PS	362	−1.245	1.221	−7.129	.248
GOVE	1337	1.979	.472	0	2.465
RQ	1337	1.969	.39	0	2.485
COC	1177	−.634	.621	−1.905	1.230

Source: Authors' own computation

studies. However, OLS and FE models often exhibit biases and inefficiencies in their estimations. For comparison and efficiency, the study uses the two-step difference GMM and two-step system GMM for robustness checks as it is more efficient and less biased than the one-step difference and system GMM. Two-step difference GMM is considered to be robust and more efficient for heteroscedasticity and autocorrelation than one-step difference GMM. A two-step system GMM is also considered more robust and efficient in heteroscedasticity and autocorrelation than a one-step system GMM. However, system GMM is preferred than difference GMM since it improves upon difference GMM by introducing more instruments to improve efficiency and transform the instruments to make them uncorrelated (exogenous) with a fixed effect. Unlike difference GMM, system GMM uses both the transformed and original equations. System GMM can also utilize the orthogonal transformation to minimize data loss (which is also applicable in an unbalanced panel). System GMM utilizes both the original equations and the transformed equation. Difference GMM yields biased and inefficient estimates, especially where T is small and also due to the poor instrument used. Hence, system GMM uses more instruments than the Difference GMM, and in the presence of heteroskedasticity and serial correlation; the Windmeijer standard error option is used. Therefore, most of the focus will be concentrated on the two-step GMM system as it is more efficient and robust than the two-step difference GMM. The two-step estimates of the difference in GMM standard errors have been shown to have a severe downward bias. The difference in GMM might also produce inefficient results, especially when there is the existence of sedulous nature independent variables (Arellano & Bover, 1995). Therefore, our study focuses on the two-step GMM system for robustness checks as it is considered to be one of the most efficient systems estimators (Law & Azman-Saini, 2012). This study's robust results mainly relied on the two-step system GMM; therefore, focusing on the two-step system GMM, the estimation of the impact of explanatory variables on CO_2 emission will be represented in Eq. (4) as follows:

$$CO_{2it} = \beta_0 + \beta_1 CO_{2i,t-1} + \beta_2 X_{i,t} + \beta_3 \text{Control}_{i,t} + \varepsilon_{i,t} \tag{4}$$

where CO_2 is CO_2 emission measured in metric tons per capita; $CO_{2i,t\text{-}1}$ is the lagged dependent variable CO_2 emission of the previous years that is affecting the current CO_2 emission.

X comprises the main independent variable of interest, such as renewable energy consumption, non-renewable energy consumption, financial development, foreign direct investment, and lists of institutional quality variables.

Control consists of several other variables such as population growth, investment measured as a gross fixed capital formation, economic growth measured in GDP per capita, and labor force. ε refers to the error term, and finally, the connotation $i(i = 1, \ldots, N)ss$ and t ($t = 1996, \ldots, 2020$) index country and time, respectively.

Results and Discussion

Findings and Discussions

Estimation of the impact of renewable energy consumption, non-renewable energy consumption, financial development, and foreign direct investment on CO_2 emission are shown in Table 4 and 5 using both static and dynamic panel models. The results for the static panel are represented in Table 4 as a base model and for comparison with the robustness tests represented in the dynamic panel model in Table 5. The robustness results that will be considered the most are presented by the system GMM as it is considered one of the most efficient and less biased estimates. To prove the validity of the instruments used and model fitness, the Sargan test and the Arellano and Bond estimation results are presented at the base of all the dynamic panel tables shown below. All the results show that the Sargan test and serial correlation tests' p-values are insignificant, and the null hypothesis cannot be rejected in all the tables. Therefore, the results support the current estimation of the study and show a non-existent serial correlation in the model. It also proves the validity of the instruments employed in the estimation, and the dynamic panel estimates are considered to be in line with the econometric theory. The results for estimating the impact of a bloc of institutional quality on CO_2 emission are presented in Table 6 and 7 for the static model (OLS, FE) and dynamic panel model (two-step difference and system GMM). Institutional quality is considered by various literature to be one of the fundamental factors in reducing CO_2 emissions since it plays a big role in setting up environmental rules and ethical behaviors to be practiced by several companies and businesses, hence promoting both green technology and sustainability. We also considered an alternative measure of Institutional quality by using only corruption as an indicator of the quality of institutions in Africa as it is one of

Table 4 Estimations of the impact of renewable energy consumption, non-renewable energy consumption, and financial development on carbon emission with a static panel

	(1)	(2)
Variables	OLS	FE
Renewable energy consumption	−0.1820***	−0.1766***
	(0.0160)	(0.0159)
Non-renewable energy consumption	−0.0512**	−0.0703***
	(0.0222)	(0.0224)
Financial development	0.1839***	0.2073***
	(0.0198)	(0.0203)
Foreign direct investment	0.0117	0.0216
	(0.0129)	(0.0133)
Economic growth	1.1376***	1.1641***
	(0.0307)	(0.0310)
Population growth	−0.0542*	−0.0414
	(0.0280)	(0.0281)
Investment	−0.1269***	−0.1175***
	(0.0317)	(0.0319)
Labor force	0.0682***	0.0823***
	(0.0131)	(0.0133)
Constant	−9.1289***	−9.5503***
	(0.3299)	(0.3375)
Observations	801	801
R-squared	0.9014	0.904
Number of years		25

***$p<0.01$, **$p<0.05$, and *$p<0.1$ indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses

OLS ordinary least square model, *FE* fixed effect model

the most fundamental problems practiced in most African countries. We estimated the impact of corruption as a proxy of institutional quality on CO_2 emission and, as presented in Table 8 and 9 for both static and dynamic panel results. Tables 10 and 11 represent the results for the estimation of the impact of technological progress on CO_2 emissions. Technological innovation is considered one of the important factors that can plummet environmental degradation by introducing sophisticated technologies that promote the use of renewable energy. Therefore, it is one of the important factors to be considered by African countries.

Renewable Energy Consumption, Non-renewable Energy Consumption, Financial Development, and Carbon Emission

Table 4 shows the estimation of the impact of renewable energy use, non-renewable energy use, financial development, and other related control variables on CO_2 emission using the OLS and FE model as a base model. We employ the dynamic panel model to confirm the robustness of the estimated results. In Table 4, renewable

Table 5 Estimations of the impact of renewable energy consumption, non-renewable energy consumption, and financial development on carbon emission with dynamic panel

	(1)	(2)
Variables	Two-step difference GMM	Two-step system GMM
Lagged CO_2 emission	–0.1704***	0.0172**
	(0.0296)	(0.0075)
Renewable energy consumption	–0.4309***	–0.2538***
	(0.1077)	(0.0260)
Non-renewable energy consumption	–0.1961***	–0.0790***
	(0.0661)	(0.0139)
Financial development	0.2460***	0.1989***
	(0.0844)	(0.0176)
Foreign direct investment	0.0119	0.0222***
	(0.0383)	(0.0078)
Economic growth	0.6850***	1.1445***
	(0.0859)	(0.0119)
Population growth	–0.3926***	–0.0413***
	(0.0786)	(0.0154)
Investment	–0.1723***	–0.1395***
	(0.0664)	(0.0288)
Labor force	0.1305***	0.0792***
	(0.0258)	(0.0046)
Constant		–8.9004***
		(0.1558)
Observations	247	761
Number of years	25	25
Sargan test	180.04(0.388)	369.09(0.960)
AR(2)	0.636	0.466

***$p<0.01$, **$p<0.05$, and *$p<0.1$ indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses

energy consumption has a negative impact on CO_2 emission both in OLS and FE. Consumption of renewable energy reduces CO_2 emission by – 0.1820 and – 0.1766 in OLS and FE models. The results are similar to that of the dynamic panel model with a difference in only their magnitudes of the coefficient. In Table 5, renewable energy consumption reduces the emission of CO_2 by – 0.4309 and – 0.2538 in two-step difference GMM and two-step system GMM, respectively. This indicates that an increase in renewable energy consumption in African countries can help mitigate the emission of CO_2, which helps promote sustainable green development. This result is similar to the findings of Azam et al. (2021), Belaid and Youssef (2017), Belaid and Zrelli (2019), Hamid (2022b), Jahanger et al., (2022a, 2022b), Khan et al., (2020a, 2020b), Khan et al. (2022), Mehmood (2021), Murshed et al. (2021), Murshed et al., (2022a, 2022b), Nathaniel et al., (2021a, 2021b), Shakib et al. (2022), and Zakaria and Bibi (2019). However, the results contradict the findings of

Table 6 Estimations of the impact of Institutional quality on carbon emission with the static panel

	(1)	(2)
Variables	OLS	FE
Renewable energy consumption	−0.4079***	−0.3231***
	(0.0789)	(0.0904)
Non-renewable energy consumption	−0.1357***	−0.1734***
	(0.0408)	(0.0445)
Financial development	0.1416***	0.1423***
	(0.0505)	(0.0518)
Foreign direct investment	0.0003	0.0026
	(0.0241)	(0.0266)
Rule of Law	0.0592*	0.0335
	(0.0349)	(0.0386)
Voice and accountability	0.0307**	−0.0273
	(0.0130)	(0.0266)
Political stability	0.0659	0.0082
	(0.0926)	(0.1015)
Government effectiveness	−0.1413***	−0.0342
	(0.0284)	(0.0527)
Regulatory quality	0.0912**	0.0451
	(0.0374)	(0.0466)
Control of corruption	0.5230***	0.4938***
	(0.0676)	(0.0687)
Population growth	0.2400***	0.2802***
	(0.0351)	(0.0398)
Investment	−0.1088*	−0.0266
	(0.0604)	(0.0659)
Labor force	0.3175***	0.3353***
	(0.0394)	(0.0437)
Constant	−3.4367***	−4.0879***
	(0.8205)	(0.9189)
Observations	145	145
R-squared	0.9542	0.961
Number of years		25

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$ indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses

OLS ordinary least square model, *FE* fixed effect model

Shah et al. (2020). Non-renewable energy consumption is seen to reduce CO_2 emission in both the static and dynamic model results, which are statistically significant. The results are unexpected and do not align with the economic theory. This may be because the majority of African countries are still poor, and energy consumption is still on the rise as economic growth increases. These results are contradictory to the findings of Jian et al. (2019), Odugbesan and Rjoub, (2020), and Siddique, (2017).

Table 7 Estimations of the impact of Institutional quality on carbon emission with static panel (alternative measure)

	(1)	(2)
Variables	OLS	FE
Renewable energy consumption	−0.3101***	−0.3030***
	(0.0219)	(0.0222)
Non-renewable energy consumption	0.0812**	0.0538
	(0.0341)	(0.0352)
Financial development	0.3318***	0.3650***
	(0.0296)	(0.0312)
Foreign direct investment	−0.0002	0.0146
	(0.0183)	(0.0190)
Control of corruption	0.1062***	0.0861**
	(0.0387)	(0.0394)
Population growth	−0.1613***	−0.1507***
	(0.0395)	(0.0400)
Investment	−0.0093	0.0027
	(0.0452)	(0.0460)
Labor force	−0.0029	0.0120
	(0.0204)	(0.0209)
Constant	−1.1592***	−1.4307***
	(0.2983)	(0.3099)
Observations	801	801
R-squared	0.8031	0.805
Number of years		25

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$ indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses

OLS ordinary least square model, *FE* fixed effect model

However, the increased non-renewable energy use can be mitigated by African countries through green technology leapfrog. African countries can leapfrog to the use of renewable energy as it boosts the economy and sustains the environment. Results on the impact of financial development on all the static and dynamic models are positive on CO_2 emissions. In OLS and FE models, financial development positively and statistically increases CO_2 emission by 0.1839 and 0.2073, and the results are statistically significant. In the dynamic panel, financial development increased CO_2 emission by 0.2460 and 0.1989 in two-step difference and two-step system GMM, respectively. These results align with the findings of Deng et al. (2022), Murshed et al. (2021), and Shakib et al. (2022). Nevertheless, the result is contradictory to the findings of Diallo and Masih (2017), Jian et al. (2019), and Raza and Shah (2018). This result indicates that the financial institutions in Africa are not enforcing strict environmental conditions through their loans to different businesses and companies, leading to increased environmental devastation. Therefore, financial institutions should start providing funding for green technology development and environmentally friendly renewable energy

Table 8 Estimations of the impact of institutional quality on carbon emission with dynamic panel

	(1)	(2)
Variables	Two-step difference GMM	Two-step system GMM
Lagged CO_2 emission	−0.1293	0.0295
	(0.0954)	(0.0451)
Renewable energy consumption	0.0369	−0.2897
	(0.5187)	(0.8227)
Non-renewable energy consumption	0.2066	−0.0828
	(0.5118)	(0.1449)
Financial development	0.0864	0.2854***
	(0.5556)	(0.0931)
Foreign direct investment	0.0570	0.0848
	(0.1460)	(0.0523)
Rule of law	1.0927**	−0.4663*
	(0.4889)	(0.2531)
Voice and accountability	−0.2515**	0.1528
	(0.1175)	(0.1452)
Political stability	−0.4042**	0.1615
	(0.1612)	(0.2688)
Government effectiveness	0.5751*	−0.3976
	(0.3287)	(0.2629)
Regulatory quality	−0.1851	0.3214*
	(0.2610)	(0.1724)
Control of corruption	−1.2187**	0.1640
	(0.4930)	(0.5571)
Economic growth	0.6600*	1.1756***
	(0.3624)	(0.1982)
Population growth	−0.8946**	−0.2641***
	(0.4173)	(0.0796)
Investment	0.0379	−0.2524
	(0.0954)	(0.1540)
Labor force	−0.1872	0.0590
	(0.1401)	(0.0372)
Constant		−9.6397***
		(3.4337)
Observations	219	669
Number of years	22	22
AR(2)	0.089	0.878
Sargan test	213.28(0.296)	590.00(0.154)

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$ indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses

Table 9 Estimations of the impact of Institutional quality on carbon emission with dynamic panel (alternative measures)

	(1)	(2)
Variables	Two-step difference GMM	Two-step system GMM
Lagged CO_2 emission	−0.2601***	−0.0250
	(0.0649)	(0.0446)
Renewable energy consumption	−0.2785*	0.2572
	(0.1555)	(0.3731)
Non-renewable energy consumption	−0.3107***	−0.1451*
	(0.0892)	(0.0754)
Financial development	0.4192***	0.3522**
	(0.1043)	(0.1397)
Foreign direct investment	−0.0171	0.0973
	(0.0447)	(0.0604)
Control of corruption	−0.5904***	−0.1898
	(0.1625)	(0.1321)
Economic growth	0.7796***	1.1245***
	(0.1340)	(0.0820)
Population growth	−0.3162***	−0.1415**
	(0.0407)	(0.0617)
Investment	−0.1413	−0.1696
	(0.1257)	(0.1104)
Labor force	−0.0231	0.0447
	(0.0418)	(0.0283)
Constant		−10.2631***
		(1.0700)
Observations	219	670
Number of years	22	22
AR(2)	0.369	0.683
Sargan test	209.29(0.462)	591.66(0.187)

***$p<0.01$, **$p<0.05$, and *$p<0.1$ indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses

projects, improving environmental quality by lowering the consumption of non-renewable energy.

The estimated coefficients of foreign direct investment (FDI) are positive towards CO_2 emission but statistically insignificant in the static panel. The impact of FDI on emission is also both positive in the dynamic panel model but only statistically significant in the two-step system GMM which is the most robust model. The findings indicate that increased FDI inflow increases CO_2 emissions in African countries. This may be true due to the recent increase in the inflow of multinational companies to African countries, which will inevitably increase energy

Table 10 Estimations of the impact of technological progress on carbon emission with the static panel

	(1)	(2)
Variables	OLS	FE
Renewable energy consumption	−0.2686***	−0.2385***
	(0.0231)	(0.0232)
Non-renewable energy consumption	0.0048	−0.0255
	(0.0372)	(0.0373)
Financial development	0.1502***	0.1995***
	(0.0376)	(0.0380)
Foreign direct investment	−0.0008	0.0193
	(0.0249)	(0.0250)
Technological progress	−0.0586***	−0.1058***
	(0.0143)	(0.0159)
Population growth	−0.1271***	−0.1085**
	(0.0438)	(0.0437)
Investment	−0.0697	−0.0624
	(0.0480)	(0.0479)
Labor force	0.0668***	0.1128***
	(0.0218)	(0.0227)
Constant	−1.3357***	−2.1339***
	(0.3413)	(0.3595)
Observations	570	570
R-squared	0.7697	0.787
Number of years		25

***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$ indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses

OLS ordinary least square model, *FE* fixed effect model

demand, worsening the environment. Secondly, the transportation of foreign goods requires lots of energy use by air, rail, road, water, and pipeline, which leads to an increase in the emission from energy use. Thirdly, most of the multinational companies that have failed to meet the environmental standards in developed companies fled to Africa due to most African countries having very weak institutional laws towards sustainability, and there is a lot of corruption, hence increasing the emission of CO_2 emission. These findings proved the Pollution Haven Hypothesis's existence in Africa. The result is in line with the findings of other studies (e.g., Balibey, 2015; Hamid, Alam, Murshed, et al., 2022a, 2022b; Jiang et al., 2018; Mert & Bölük, 2016). However, the results are contradictory to the findings of Jebli and Youssef (2015) and Zhu et al. (2016).

The estimated economic growth coefficients are positive and statistically significant on CO_2 emission in all the static and dynamic models. This implies that for growth to occur, energy consumption is inevitable, drastically leading to CO_2 emissions. The

Table 11 Estimations of the impact of technological progress on carbon emission with dynamic panel

	(1)	(2)
Variables	Two-step difference GMM	Two-step system GMM
Lagged CO_2 emission	−0.1055	−0.1853**
	(0.1098)	(0.0883)
Renewable energy consumption	−0.4944***	−0.6136***
	(0.1347)	(0.1848)
Non-renewable energy consumption	−0.0540	−0.1917*
	(0.1728)	(0.1089)
Financial development	0.0185	−0.0424
	(0.2443)	(0.1281)
Foreign direct investment	−0.0144	−0.0766
	(0.1689)	(0.1247)
Technological progress	−0.0508	−0.0191
	(0.0606)	(0.0333)
Economic growth	0.6630***	0.9114***
	(0.0977)	(0.1421)
Population growth	−0.4138**	−0.0463
	(0.2075)	(0.1090)
Investment	−0.0944	−0.4139**
	(0.0861)	(0.1624)
Labor force	0.1254***	0.1218***
	(0.0431)	(0.0195)
Constant		−4.3289*
		(2.3261)
Observations	219	542
Number of years	22	25
AR(2)	0.151	0.342
Sargan test	216.85(0.323)	459.22(0.6204)

***$p<0.01$, **$p<0.05$, and *$p<0.1$ indicate significance at the 1%, 5%, and 10% levels, respectively. Standard errors are in parentheses

results are in line with the literature (e.g., Chishti et al., 2022; Farooq et al., 2022; Hamid, Alam, Murshed, et al., 2022a, 2022b; Murshed et al., 2021; S. P. Nathaniel et al., 2021a, 2021b; Ozturk et al., 2022; Rehman et al., 2022; Shakib et al., 2022). An increase in population growth decreases emissions, as shown by the estimation results in the entire model. This may be due to the under-utilized labor population in Africa due to the limited capital and investment in Africa. The result is contradictory to the findings of Rehman et al. (2023). Investment has a negative statistical impact on CO_2 emission. This implies there has not been enough investment to trigger CO_2 emissions. Therefore, future investments should consider the use of renewable energy to encourage sustainable development in Africa. The labor force is seen to act as a driver of CO_2

emission. And the results are all statistically significant in all the models. The result is in line with the findings of Jahanger et al., (2022a, 2022b).

Institutional Quality and CO_2 Emission

Tables 6 and 7 show the estimation of the impact of institutional quality on CO_2 emission using the base model. Table 6 focuses on the impact of a bloc of institutional quality on CO_2 emission, while Table 7 focuses on an alternative measure of the impact of one Institutional quality (corruption) since it is one of the fundamental in Africa and is a main problem in most of the African countries. Therefore, its impact is so fundamental in the determination of environmental quality. The coefficient estimates of renewable energy are constant for both Table 6 and 7. After the addition of institutional quality in the models, renewable energy exhibits a significant negative impact on CO_2 emission, which shows the importance of institutional quality and its important role in mitigating CO_2 emission and improving the environment. An increase in renewable energy use reduces emissions by − 0.4079 and − 0.3231 in Table 6, both in OLS and FE. And by − 0.3101 and − 0.3030 in Table 7 in the static models. Our results are, however, contradictory to the findings of Apergis and Payne (2010), Bilgili et al. (2016), and Jebli et al. (2019). Likewise, the impact of non-renewable energy use, similar to the findings in Table 4 and 5, still has reduced emissions and is statistically significant in both models in Table 6 and 7 in the presence of institutional quality. The results are contradictory to the finding of Khan et al., (2020a, 2020b), Nathaniel et al., (2021a, 2021b), and Shakib et al. (2022). Financial development has a positive and significant impact on environmental pollution, even with the presence of institutional quality. This implies that the legal and political systems in Africa are still weak to instill good quality regulation on financial institutions to promote green development (Hamid et al., 2022a, 2022b).

Similarly, FDI also positively impacts environmental pollution in the presence of institutional quality, though statistically insignificant. Population growth and labor force positively affect environmental pollution in the presence of institutional quality in African countries and the results are statistically significant. Therefore, institutional quality needs to be strengthened in Africa to curb the magnitude of pollution.

We look at how institutional quality affects the environment. First, we investigated the impact of all institutional quality on environmental quality. It is believed that government institutions, especially the legal and political systems, play a fundamental role in mitigating CO_2 emissions (Hamid et al., 2022a, 2022b). Therefore, this study employs the impact of institutional quality, such as the rule of law, voice and accountability, political stability, government effectiveness, regulatory quality, and control of corruption on African environmental quality. The estimated results of the impact of the rule of law on CO_2 emission are positive and significant in OLS but insignificant in the FE model. This shows that Africa's available rules and laws for managing the environment and preventing pollution are still very weak. Therefore, the rule of law in Africa needs to be improved. The estimated results of voice and accountability indicate that there is a positive effect of voice and accountability on the emission of carbon in the OLS model and it is statistically significant. However, the result is negative and insignificant in the FE model, which leads to a mixed conclusion. Political stability has a positive but insignificant impact on environmental quality. The results of government effectiveness show that it reduces environmental pollution in Africa, implying that government effectiveness has enough roles in environmental protection. However, the result is insignificant in the FE model. Regulatory quality has a positive impact on environmental pollution, which implies that the African government's regulatory quality has not reached the standard of environmental protection; therefore, there's a need for improvement. Similarly, control of corruption is positive and significant in both Table 6 and 7. Corruption has a positive and significant impact on environmental degradation in African countries both in the static models. This finding is in line with the findings of Hamid et al., (2022a, 2022b). This indicates that there is still the presence of high bribery and use of power for personal benefit between government officials in African countries at the expense of environmental protection. Therefore, there is still a need to curb corruption to improve environmental quality in Africa.

For robustness check, we estimated the two-step difference GMM and two-step system GMM as presented in Table 8 and 9 below. For more unbiased and consistent estimates, we report the two-step system GMM than the two-step difference GMM. In Table 8, the coefficient of the lagged CO_2 emission is positive and statistically insignificant in the two-step system GMM. The sign shows that the past emission increases the current emission by 0.0295. The estimated coefficient of renewable energy use reduces environmental pollution by -0.2897, though it is not significant. The results are consistent with the base model, which indicates that increased renewable energy consumption improved environmental quality in Africa. The sign of the effect of non-renewable energy consumption is still similar to that of the base model, though statistically insignificant. Financial development results are still positive and significantly have an impact on environmental pollution. This calls for African leaders and financial institutions to work together towards enforcing green technologies in all their programs and policies. Foreign direct investment increases environmental degradation in Africa as their coefficient is positive in both the static and dynamic panels. This indicates that FDI inflow brings together development with pollution, thereby proving the Pollution Haven Hypothesis. Therefore, strict environmental policies should be set and abided by the FDI to promote sustainable development in African countries. Corruption estimates exhibit mixed results. A 1% increase in economic growth is seen to increase CO_2 emission by 1.1245 in Table 8, and the result is consistent with static panel results. These results are in line with the findings of other studies (e.g., Balibey, 2015; Deng et al., 2022; Dogan et al., 2017; Murshed et al., 2021; Omri, 2013; Peng et al., 2016; Shakib et al., 2022).

Therefore, precaution should be taken on the kind of energy demand concerning Africa's economic growth increase. More effort should be diverted towards the use of renewable energy for sustainable growth. In Table 8, corruption positively impacts environmental degradation, whereas in Table 9, where corruption is a proxy of institutional quality, it has a negative impact on environmental pollution. Control of corruption has been chosen independently due to its potential influence on CO_2 emissions in Africa. Therefore, the government should encourage control of corruption since it improves environmental quality by lowering CO_2 emissions. Variables such as investment, population growth, and labor force exhibit the same impact as the static panel results, confirming the models' robustness check.

Technological Progress and CO_2 Emission

The estimated coefficients of the impact of renewable energy consumption on carbon emission are homogenous throughout the three models. It is still observed that renewable energy use has a negative and significant impact on environmental pollution even after the addition of technological progress. Non-renewable energy use still exhibits a negative and significant impact on emissions after the addition of technological progress. This implies that technological innovation encourages the use of green technology, reducing the consumption of fossil energy in Africa. The estimated coefficient of financial development on environmental pollution in the two-step system GMM after the addition of technological progress is negative and insignificant, which is not the same as the above models. Foreign direct investments also exhibit a negative and insignificant impact on pollution after the addition of technological advancement. Therefore, technological development has a significant impact on environmental quality. The estimated coefficient of technological progress indicates that technological progress has a negative and significant impact on pollution in Table 10 and also a negative impact using the dynamic panel. This implies that African financial, foreign, and government institutions should encourage and focus on improving technological innovation to attain sustainable development in a quality environment. These results are in line with the findings of Ali et al. (2016), Cheng et al. (2017), and Zhang and Xu (2016). Economic growth still positively and significantly impacts environmental pollution, similar to the above, hence proving the EKC hypothesis. This is true even after the addition of technological progress. This is because most African countries are poor and are, therefore, on the rise to economic growth, which requires greater energy demand. However, there should be a shift towards greener technology to have sustainable growth. Results regarding the impact of population growth, investment, and labor force are still the same as the first and second models, even after the addition of technological progress, which acts as a robustness check for the above model.

Conclusion and policy recommendations

The current study investigates the impact of renewable, non-renewable, financial development, and foreign direct investment on environmental quality (CO_2 emission) by considering the contribution of institutional quality and technological progress. The study utilizes panel data for all 54 African countries for the period 1996 to 2020. The study explored the data collected from the World Development Indicator of the World Bank. Our study makes use of three models. The first model looks at the impact of renewable energy consumption, non-renewable energy consumption, financial development, and foreign direct investment on environmental quality (CO_2 emission). The second model exploited the impact of the above variables with the inclusion of institutional quality towards CO_2 emission. The third model augmented technology development with renewable energy consumption, non-renewable energy consumption, financial development, and FDI and investigated its impact on CO_2 emission. The results of the overall models above indicate that renewable energy consumption has a negative impact on CO_2 emission.

Similarly, non-renewable energy consumption conveys a similar impact as renewable energy consumption on CO_2 emission. This may be the case because most African countries are very poor and, therefore, utilize a limited amount of energy. However, the energy consumption volume is seen to rise in most of the highly industrialized and developing parts of the regions like the north and south, hence indicating the rise in energy demands. Our finding shows that financial developments positively impact CO_2 emission; however, the sign for financial development changes after the addition of technological progress in the last model. FDI has a positive and significant impact on environmental pollution in model one, which confirms the PHH hypothesis. In model 2, the estimated coefficient of FDI is still positive on CO_2 emission after the addition of institutional quality. However, it's statistically insignificant. For model 3, FDI has a negative impact on environmental pollution after the inclusion of technological progress. This implies that technological innovation plays fundamental tools in FDI operations to promote sustainable productivity in the host country. Economic growth has a positive and significant impact on environmental pollution in all three models, proving the existence of the EKC hypothesis in Africa. This is because most African countries are still poor and are, therefore, on the rise to economic growth, which requires greater energy demand. In model 2, institutional qualities are added to investigate their impact on environmental pollution. The majority of the institutional quality estimates are significant for reducing the environmental pollution in the dynamic panel; however, some are positive or insignificant for reducing environmental pollution, which shows that there are still lots of African countries with poor legal and political systems that need to enhance environmental quality as well to meet the sustainable economic growth. The results of technological progress show a negative impact of technological advancement on environmental pollution. Although it is significant in the base results and insignificant in the dynamic panel. Technological advancement acts as a tool for mitigating pollution by introducing green technology, which promotes sustainable growth and environmental protection. Therefore, all African countries must promote and invest in technological advancement towards green technology or leapfrog from other developed nations to promote sustainable development.

The policy recommendation from this study is that, accordingly, to decarbonize the economy, this study recommends the African government adopt necessary policies for fostering renewable energy transition within the energy sector, greening the trade globalization strategies, achieving environmentally sustainable economic growth, developing the financial sector by introducing green financial schemes, planning sustainable urbanization, and financing technological development-oriented projects. Nonetheless, African governments should adopt win–win strategies to reduce greenhouse gas emissions. For instance, introducing solar energy and other creative and cost-effective technologies to promote sustainable growth. African Environmental Bureau of Standards should continue to implement and enforce the utilization of renewable energy to promote sustainable green development. Therefore, policymakers must encourage the use of renewable energy rather than non-renewable energy to stimulate sustainable development. The government should also support and encourage technological innovation since it reduces environmental degradation and encourages sustainable growth. Furthermore, African countries need to strengthen institutional quality since it is critical in promoting environmental quality and sustainable growth.

Our study is limited to data availability, variables, and methodology used. Future studies should consider using data with more dimensions, more adjusted variables, and more sophisticated methods. Future studies should also consider utilizing country-specific data to confirm the validity of the findings for a single African country. The methodology used in this study is so limited, including OLS and GMM techniques. Future studies should consider using sophisticated estimation techniques like panel ARDL or QARDL techniques to check the nexus amid the variables.

Appendix

See Table 12 and Figs. 8 and 9

Table 12 Correlation

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) CO_2	1.000															
(2) REC	−0.713*	1.000														
(3) EC	0.563*	−0.426*	1.000													
(4) FD	0.492*	−0.353*	0.303*	1.000												
(5) FDI	0.162*	−0.053	0.002	0.051	1.000											
(6) RL	0.430*	−0.157	0.018	0.496*	−0.045	1.000										
(7) VA	0.058	−0.055	0.200*	0.054	0.138*	−0.045	1.000									
(8) PS	0.420*	−0.409*	0.170*	0.376*	0.090	0.502*	−0.156*	1.000								
(9) GOVE	0.087*	−0.070	0.181*	0.143*	0.173*	0.016	0.887*	−0.104	1.000							
(10) RQ	0.087*	−0.065	0.207*	0.109*	0.148*	−0.046	0.866*	−0.150*	0.949*	1.000						
(11) COC	0.147	−0.166	0.181	0.166	0.039	0.348*	−0.078	0.317*	−0.023	−0.046	1.000					
(12) TECH	−0.116*	0.051	0.135*	−0.053	−0.125*	−0.090	−0.128*	0.071	−0.241*	−0.167*	−0.118	1.000				
(13) GDP	0.935*	−0.659*	0.586*	0.434*	0.187*	0.508*	0.076*	0.472*	0.108*	0.094*	0.226*	−0.085	1.000			
(14) POPG	−0.392*	0.335*	−0.070	−0.402*	0.079*	−0.436*	0.084*	−0.341*	0.029	0.065	−0.068	0.125*	−0.336*	1.000		
(15) INV	0.360*	−0.266*	0.218*	0.245*	0.269*	0.310*	0.067	0.229*	0.121*	0.093*	0.329*	−0.141*	0.388*	0.024	1.000	
(16) LF	−0.219*	0.032	0.303*	−0.026	−0.093*	−0.561*	0.313*	−0.391*	0.297*	0.322*	−0.153	0.216*	−0.263*	0.200*	−0.044	1.000

***$p<0.01$; **$p<0.05$; *$p<0.1$

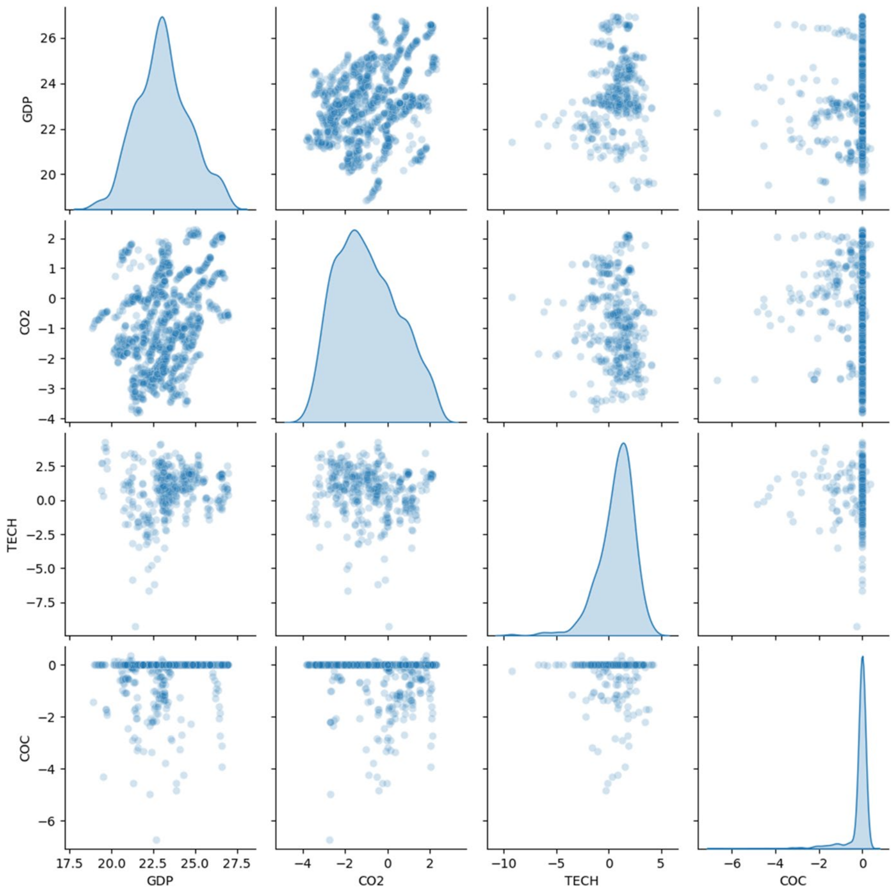

Fig. 8 Authors' own computation

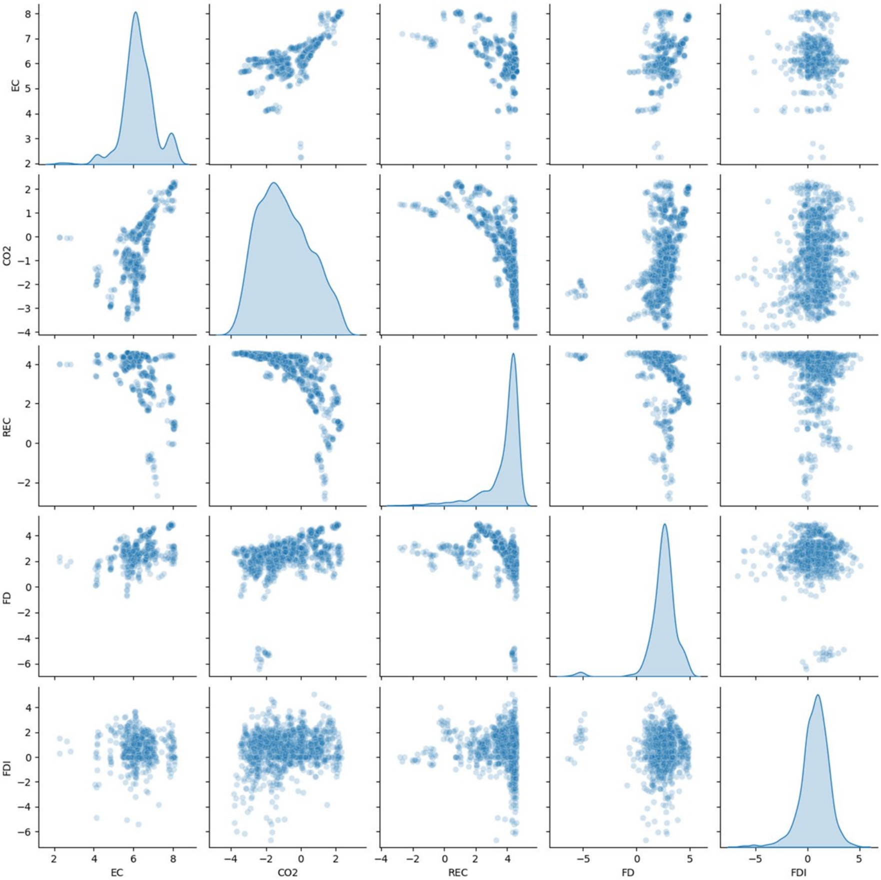

Fig. 9 Authors' own computation

Acknowledgements The author would also like to thank his supervisor, Professor Shen Qianling, for her assistance with the research. The author wishes to thank anonymous reviewers and editors for their remarks; nonetheless, the author is solely accountable for the consequences of this article.

Author Contribution Henry Orach (orachhenry68@gmail.com): writing and original draft preparation; investigation; writing, review, and editing; conceptualization; methodology; software; and formal analysis. Shen Qianling (qianling@sicau.edu.cn): supervision; writing and original draft preparation. Salina Adhikari Sharmasalina20@gmail.com): methodology and writing, review, and editing. Martinson Ankrah Twumasi (twuma2012@sicau.edu.cn): conceptualization and methodology and writing, review, and editing. Abbas Ali Chandio (alichandio@sicau.edu.cn): writing, review, and editing. Peter Ocheng (opiocheng@yahoo.com pocheng@umu.ac.ug): supervision, writing, review, and editing. Amone William (amonewb@gmail.com): supervision, writing, review, and editing. Anita Afra Arthur (anitaarthur4@gmail.com): the revision and inspection of the manuscript and addition of literature review. Buteme Irene Masangah (ibuteme@mubs.ac.ug): the revision and inspection of the manuscript and addition of literature review.

Data Availability The datasets used and analyzed during the current study are accessible upon reasonable request from the corresponding author.

Code Availability Not applicable.

Declarations

Ethics Approval Not applicable.

Consent for Publication Not applicable.

Conflict of Interest The authors declare no competing interests.

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