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RESEARCH ARTICLE

Dynamic assessment of the impact of agricultural land use change and globalization on environmental quality in the tropical African Rainforest: evidence from the Congo Basin

Mohamed Yufenyuy[1] · **Saltuk Pirgalıoğlu**[2] · **Orhan Yenigün**[1,3]

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Abstract
The rising human demand for food has increased the pursuit for more agricultural land to feed the ever-growing human population. Although agriculture constitutes the cornerstone of most economies and serves as a vital source of foreign earnings to others, experts suggest that it emits a substantial amount of greenhouse gases into the atmosphere, thereby enhancing global warming. Furthermore, with the growing pace of globalization, less developed countries are witnessing economic growth with detrimental impacts on the environment. Inspired by the need to protect tropical rainforests and basins, the current research aims to assess the dynamic impacts of agricultural land use change (LALUC) and globalization (LGLO) on environmental quality (LCO_2) in the Congo Basin while controlling for economic growth (LGDP), biomass energy consumption (LBIO), and urbanization (LURBN). Based on panel data from 1980 to 2018, this study utilized second-generation econometric methods including the cross-sectional Im, Peseran Shin (CIPS), Westerlund bootstrapped co-integration test, autoregressive distributive lag/pooled mean group (ARDL/PMG), and the Dumitrescu Hurlin (D-H) panel causality estimates. The outcome reveals a long-run equilibrium co-integrating association among the estimated variables, and LALUC, LBIO, and LURBN were found to reduce LCO_2, while LGDP and LGLO increase LCO_2. These findings imply the inverted U-shaped relationship between LALUC, LBIO, and LURBN is beneficial for environmental quality in the Congo Basin. Based on the findings, environmental quality and economic growth can be achieved instantaneously in this region by engaging in large-scale production of biomass energy. Therefore, policymakers and governments should promote renewable energy use and convey foreign funds towards its enhancement, while investments in agriculture should prioritize environmentally benign practices such as agroforestry.

Keywords Agricultural · Congo Basin · Globalization · Land use change · Environmental quality · Carbon dioxide emissions

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✉ Mohamed Yufenyuy
papahodja@gmail.com; 174625@std.eul.edu.tr

Saltuk Pirgalıoğlu
spirgalioglu@eul.edu.tr

Orhan Yenigün
yeniguno@boun.edu.tr

1 Department of Environmental Sciences, Institute of Graduate Studies and Research, European University of Lefke, Lefke, Northern Cyprus, TR-10 Mersin, Turkey

2 Environmental Engineering Department, Engineering Faculty, European University of Lefke, Lefke, Northern Cyprus, TR-10 Mersin, Turkey

3 Institute of Environmental Sciences, Boğaziçi University, Bebek, Istanbul 34342, Turkey

Introduction

Over the years, economies have chosen to pursue viable growth pathways by aligning their objectives to the three facets of sustainable growth and development, which covers social, economic, and environmental aspects. Nevertheless, environmental conservation has persistently become a subject of debate among scholars (Adebayo et al. 2022a; Adedoyin et al. 2020). Human activities are transforming our planet at an unprecedented pace and scale, causing global environmental change (Isik et al. 2021a). The transformation is intended to increase economic growth and profit for governments and private companies. However, these human actions result in increasing carbon dioxide (CO_2) concentrations, contamination, and land abandonment, as well as declining rural life since land is one of the primary assets that sustain livelihoods in rural areas (Lu 2016). As CO_2 and other undesirable gases continue to fill the atmosphere, the effects on humans, ecosystems, and agricultural productivity become obvious, resulting in the expansion of arable lands (Baig et al. 2022). Therefore, air pollution reduction measures and efforts are urgently needed to fight climate change (Awazi et al. 2022; Yufenyuy and Nguetsop 2020; Baig et al. 2023) and lessen the nefarious global warming effects (Kirikkaleli and Adebayo 2021; Aydoğan and Vardar 2020a). Reducing fossil fuel usage is primordial since it features prominently as a key driver of global climate change. In the meantime, over 80% of global primary energy needs are satisfied through fossil fuels trade notably crude oil, coal, and natural gas (Wang et al. 2022; Zhong et al. 2017) thereby contributing to about 75% of global GHG emissions (Awosusi et al. 2022). Nevertheless, pollution-free energy sources like biomass, and geothermal, among others, have recently been endorsed and promoted because of their vital role in boosting environmental quality (Kirikkaleli et al. 2022; Gao and Zhang 2021; Destek and Sinha 2020; Dogan and Inglesi-Lotz 2017). Consequently, the rapid growth in renewables is currently at their peak owing primarily to the rapid progress in scholarly research, technological innovation, energy efficiency, and collaborative regulations (Ahmad et al. 2023; Adebayo and Kirikkaleli 2021).

Research on land use change has been a subject of contention among scholars in recent years with agricultural and forest lands being the focal points as they both constitutes the two major land uses across the globe (Carter 2018). As a result, the agricultural sector constitutes the main stay of most countries (Baig et al. 2023a) and a valuable activity across the globe. For instance, 36% of global land is used for agriculture (IPCC 2021), whereas world agricultural output stood at \$1.3 trillion in 1980 and \$3.8 trillion in 2021. Studies suggest that agricultural-based activities such as overgrazing, deforestation, and the transformation of pastures into arable lands for farming enhances global greenhouse gas (GHG) emissions (Fopa et al. 2023; Yurtkuran 2021; Friel et al. 2009; Bellarby et al. 2008). Accordingly, reports by the IPCC submits that the agricultural sector releases roughly 36% of global GHGs, while CO_2 emissions from agriculture, forestry, and related land uses stood at 13% and ranked second amid all the other sectors (IPCC 2021).

In the Central African region, annual CO_2 emission from deforestation varies from 20 to 60 million tons (WWF 2022). The World Wide Fund (WWF) predictions in the region indicate that by 2050 the cutting of trees in the Democratic Republic of Congo (DRC) alone is likely to emit more than 30 billion tons of CO_2, which is almost equal to the UK's CO_2 emission over the past six decades. In the Congo Basin, agricultural extension constitutes one of the proximate drivers of deforestation and forest degradation characterized by permanent farming (large versus small scale and commercial versus subsistence), shifting cultivation (slash and burn), bush fallowing, and animal raising (large vs. small scale) (Tegegne et al. 2016). Although the transformation of forest to agricultural land comes with socio-economic gains, Kishor and Lescuyer (2012) concludes that such transformation reduces forest cover and affects biological soil properties, thereby increasing CO_2 emissions. In this process, ecosystem services are depleted thus destabilizing the biogeochemical recycling and plant growth. Therefore, investigating the impacts of agricultural land use change on CO_2 emission may proof insightful for policy decision-making in this region.

Globalization and environmental quality nexus have been a subject of research in recent decades, receiving considerable policy focus which directly relate to heated debates over the "pollution haven hypothesis (PHH)." This theory suggests that uprising countries receiving pollution-intensive corporations from the advanced world have less stringent environmental regulations (Majeed and Mazhar 2019). Historically, major globalization studies have focused on assessing globalization with foreign funds and ignoring the non-financial aspects of it (Frankel 2003), while others have essentially ignored the impacts of globalization on CO_2 emissions and focused largely on converging cultures, building regional and economic partnerships, and economic growth. For several decades, since global warming has become an existential threat to humanity, scholars have given more attention to examining the nefarious effects of globalization on the environment (Farooq et al. 2022; Liu et al. 2020; Osland et al. 2002). While some scholars claim globalization has good benefits (open economies) by propelling growth and development as evident in advanced economies, there are several researchers who argue that it is the source of deforestation, as it heightens atmospheric CO_2 concentrations and compromises environmental quality (Anderson et al. 2019). Similarly, many countries have given praises to the few most globalized nations based on the globalization indices. However, it is worth noting that being more globalized does not necessarily entails having a positive outcome. Consequently, the more globalized a country is, the more pressure it exerts on the ecosystem either domestically or across its national boarders, which is a limiting factor to sustainability (Bilgili et al. 2020). Given these scenario, sustainable land use and economic globalization have become one of the key global policy objectives (Robinson and Carson 2015).

The Congo Basin has been a trading partner with the external world since the colonial epoch and among global tropical rainforests, Congo Basin is home to the second-largest mosaic in the world and has the greatest carbon absorption potential internationally (The World Bank Group 2022). However, its carbon repossession capacity is fast diminishing because of continuous forest cutting (Tongele 2021). It is heavily endowed with almost 178 million hectares (ha) of dense tropical forest with about one-third set aside for timber production, 18 million ha as reserve, and 100 million ha yet to be allocated (Tritsch et al. 2020). Despite these rich endowments, the high involvement of Congo Basin countries in foreign trade through the phenomenon of globalization has yielded disproportionate outcome for its wood processing industries. As a result, wood from this Basin has been exported to foreign nations in its raw form over the last six decades with negligible secondary to tertiary transformations. For instance, the entire Basin occupies a very minimal position in the timber industry globally thus, accounting for just 1% of world's sawn wood production, 1% the entire production of tropical plywood, 5% of global production of tropical logs, about 6% of the overall tropical sawn wood production, and 7% of global veneer production (African Natural Resources Centre (ANRC 2021)). In addition, secondary and tertiary trade balances in the Basin from 2010 to 2019 were largely negative amounting to over US$1.15 billion for wood product, with wooden furniture bearing the greatest brunt with 81% (as a secondary product). While the tertiary sector registered a massive negative trade balance summing up to US$797.68 million with a yearly mean trade deficit of US$80 million. As a result, continuous deforestation increases CO_2 emissions while the subsequent transformation of previous forest covers into cultivable space and other land uses could be because of distant drivers such as globalization.

Studies incorporating agricultural land use change and CO_2 emissions are varied and inconclusive. Most of these investigations are country-based and are analyzed in multifaceted ways. Additionally, very few scientific studies carried out in the framework of developed, developing and emerging economies are panel-based. For instance, Waheed et al. (2018) found that agricultural value added enhances environmental quality by reducing CO_2 emissions in Pakistan. Similar findings were reported in the North African panel study (Jebli and Youssef 2017) and in the panel of high, medium and low-income nations (Rafiq et al. 2016). However, a fresh research by Usman et al. (2022) noticed a positive association between agricultural value added and CO_2 emissions in South Asian countries.

Moreover, while varied scientific studies have investigated globalization's effects on CO_2 emissions across the world, less attention has been channeled to tropical basins. In addition, a wholesale of studies assessing the effects of globalization on the environment are country-based and only a few of these studies dwelled on multiple countries. Matson et al. (1999) researched the role of globalization on Nitrogen deposition in tropical environments, while Jahanger (2022) studied the impacts of globalization in 78 countries both within and outside the tropics and resulted in the conclusion that globalization in all its forms heightened CO_2 emissions across Africa, Asia, Latin America, and the Caribbean. A huge knowledge gap still exists pertaining to the role of globalization on CO_2 emission in the tropical world

Given this contextual background, the global quest for sustainable agriculture and land use policy as well as the worldwide partnership for the attainment of the UN sustainable development Goals places the following interrogations to academia: (i) Does any causal link exist between agricultural land use change, globalization, and environmental quality? Can the effect of agricultural land use change and globalization on the environment be a policy framework for sustainable development? Can globalization and agricultural land use change affect carbon dioxide emissions? To respond to these questions, the Congo Basin presents a relevant case study to assess the dynamic impacts of agricultural land use change and globalization on environmental quality. It is instructive to recognize that for several decades; partnerships beyond national borders have played a massive role in fostering scholarly research and forest policy design. While such cooperative actions have improved expert understanding of the carbon economy, forest ecology, wildlife spatial distribution, human role in local forest governance, and management from multiple perspectives, countries in the Congo Basin are yet to have clear-cut forestry policies. This could be due to a lack of research incorporating CO_2 emissions and its determinants in this region thus, making global policymakers pay less attention to emissions from this region.

The current study intends to bridge the gap in research as it pertains to the role of globalization and agricultural land use change on CO_2 emissions in humid tropical Africa, bring clarity to the lingering debates and provide recommendations for policy actions. Such studies are limited in the Congo Basin, which is a huge environmental hotspot because of its vital role as the world's largest carbon sink. Moreover, the deficiency of research integrating agricultural land use change and globalization on CO_2 emission is not the only motivation of this study. Combining and assessing the role of biomass energy consumption, economic growth, and urbanization constitute an additional drive, given that such research is essential for the Congo Basin and the tropical world as a whole. Figure 1 and 2 depict historical trends in agricultural land use change and globalization for the Congo Basin respectively.

Six territories with enormous tree cover are integral to the Congo Basin (CB), namely, Gabon, Cameroon, Equatorial Guinea, Central African Republic, DRC, and the Republic of Congo. Of these six territories, the DRC occupies the greatest portion of the rainforest, which span over 100 million hectares, amounting to about 60% of lowland forest cover in Central Africa. Local populations rely on these forests for livelihood sustenance, while the global community considers it as a shield for biodiversity and climate change extenuation (Aquilas et al. 2022). Additionally, the Congo Basin is

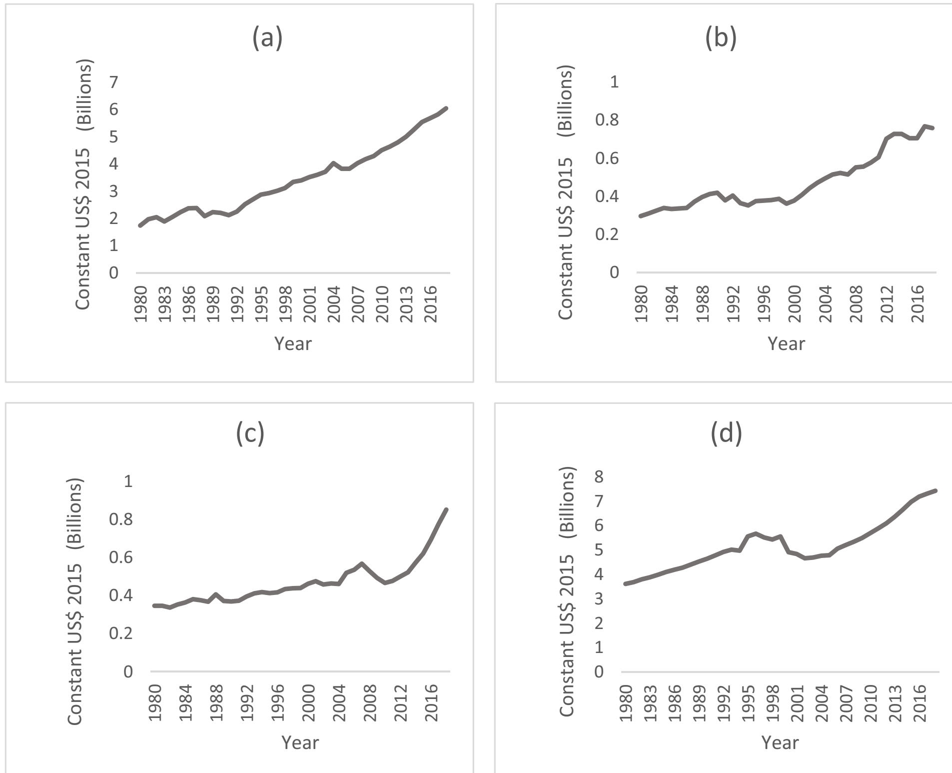

Fig. 1 Agriculture, forestry, and fishing value added (proxy for Agricultural land use change). **a**, **b**, **c**, and **d** represents Cameroon, Congo, Gabon, and DR Congo, respectively

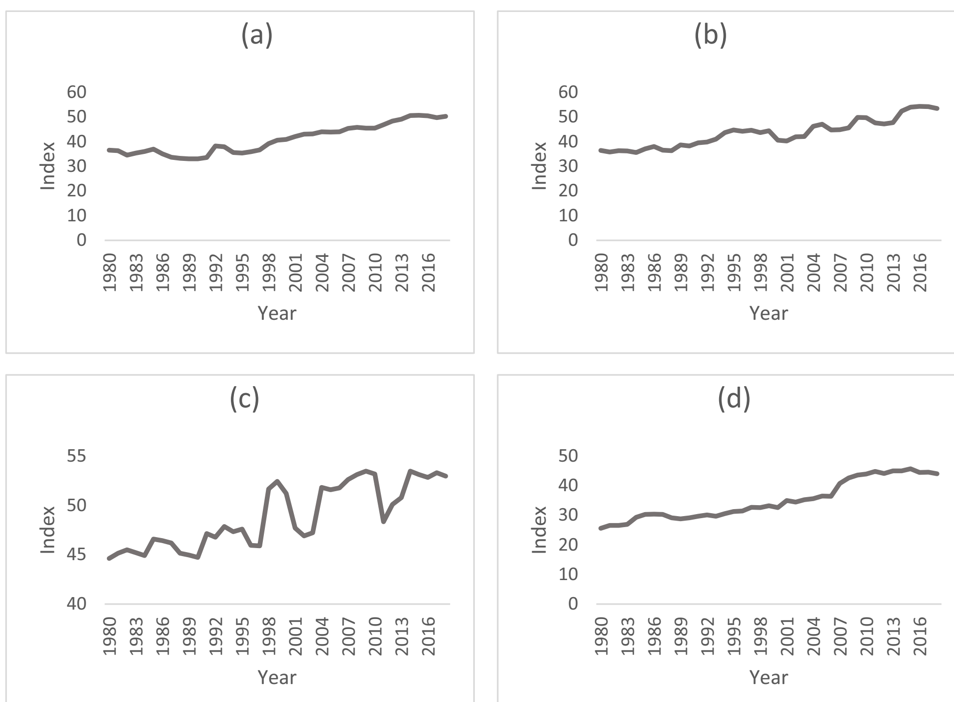

Fig. 2 Globalization. **a**, **b**, **c**, and **d** represents Cameroon, Congo, Gabon, and DR Congo, respectively

renowned for its rich biodiversity and researchers have found that it generally harbors taller trees within lower densities of smaller trees as opposed to forests in Latin America (Abernethy et al. 2016).

This study is of great importance in that assessing the effects of agricultural land use change and globalization on CO_2 emissions while controlling for growth, biomass energy usage, and urbanization could be a major objective for policymakers in the Congo Basin Forest region. Thus, it adds to the 2050 global net zero greenhouse gas emissions (GHG) emissions policy goal initiated by the EU member states. Again, Congo Basin members' states need a vigorous policy framework that would enable them to stay put on achieving net zero GHG emissions by the year 2050 in order to preserve its rich biodiversity. Furthermore, in political debates, environmental sustainability issues are habitually regarded as a hindrance to economic growth and development; thus, economies are recurrently anxious over their growth process and ways of addressing it. To remediate this challenge, the outcomes of this research will grant environmentalists, policymakers, and economists in the Congo Basin a vigorous policy pathway towards achieving growth without compromising the quality of the environment.

This research also aligns with the objectives of the 2015 Paris Agreement as well as the 13th, 15th, and 17th Sustainable Development Goals (SDGs). In Glasgow, ambitious redesigned goals were adopted (Galpern 2021). In the recent COP27 Climate Change Conference in Sharm El-Shike (November 20th, 2022), the host country, Egypt, declared the event as the "Implementation COP" which emphasized that countries convey goals into action. Thus, COP27's main provision was the "loss and damage" fund for susceptible developing nations as a remedy to reduce emissions and responding to the damage caused by the nefarious impacts of climate change. Thus, Congo Basin countries stand a greater chance of benefiting from the "loss and damage fund" if their environmental policies are well coordinated and attractive to the international community. Lastly, no studies on agricultural land use change and globalization have focused on the Congo basin, which has recently attracted international attention with several projects including Nationally Determined Contributions (NDC), Forest Law Enforcement, Governance and Trade (FLEGT), and Reducing Emissions from Deforestation and forest Degradation (REDD+). Therefore, findings from this research will serve as a benchmark for establishing suitable energy policies, enhancing global environmental collaboration, and building eco-friendly negotiations for member states of the Congo Basin that would aid in achieving environmental sustainability. Additionally, the limitations on nascent empirical investigations of panels suggest the use of dynamic and advanced econometric approaches such as CIPS/CADF, Westerlund cointegration, ARDL/PMG, and Dumitrescu Hurlin causality estimators. The study progresses as (i) next section is literature review; (ii) the review will be followed by "Methodology"; (iii) the fourth section is empirical outcomes and discussions; (iv) the fifth and sixth sections is the conclusion and policy recommendation.

Review of the related studies

This section centers on the review of previous empirical studies as it pertains to the role of globalization, agricultural land use change, biomass energy use, urbanization, and economic growth on environmental quality. In past environmental studies, numerous scholars have examined factors that cause increases in environmental pollution. As a result, in the early 1990s, several evidenced-based researchers sought to explain this situation, focused first on the relationship between per-capita income and environmental degradation, and reported an inverted U shape (Grossman and Krueger 1991; Panayotou 1995). With the introduction of energy consumption as a determinant, Panayotou (1995) introduced the EKC hypothesis, and explained that initial stages of economic growth are characterized by inefficient use of resources and environmental degradation due to increasing industrial production. Nevertheless, after a certain threshold, the social consciousness of pollution arises and the demand for a clean environment accordingly increase. This demand for industrial environmental responsibility usually results in the full deployment of environmentally friendly technologies for production, leading to reduced environmental pollution (Işık et al. 2021c). However, the EKC has been criticized for its prime focus on the environment.

In recent years, several empirical studies have used CO_2 as an indicator for environmental degradation in the environmental Kuznets curve (EKC) literature (Isik et al. 2021a, b; Dogan and Turkekul 2016). These environmentalists believe that an upsurge in GHG emissions, especially CO_2E, constitutes the key driver of climate change. As a result, CO_2 emissions have become an increasingly relevant topic of discussion among scholars because of its negative impacts on the environment (Baig et al. 2023; Işık et al. 2021b). At the Paris Conference (COP-21), climate change and renewable energy featured prominently as the key topic, instructing world leaders to take urgent actions that would save the planet Earth from global warming. Here, the essential factor is to comprehend how energy efficiency affects CO_2E in achieving sustainable economic development. However, the relationships between CO_2E and globalization, urbanization, and agriculture are complicated and controversial and warrant serious consideration. Studies that have examined these relationships in part included Kirikkaleli et al. (2021) and Raza et al. (2021). and there are several others.

Based on these reviews, we make the following hypothesis towards the assessment of the effect of agricultural land use change and globalization on environmental quality in the Congo Basin. To realize this objective, the study controls for urbanization, economic growth, and biomass energy consumption which have been found in literature to relate to carbon dioxide emissions across the world (Raihan and Tuspekova 2022; Kongkuah et al. 2022).

H_1: Growth in globalization has positive effects on environmental degradation

Globalization is measured through trade openness, and encompasses economic, political, and social activities (Sebri and Ben-Salha 2014; Shahbaz et al. 2017a, b). Since the early 1980s, there has been significant advancement in the globalization process characterized by well-known socio-economic, cultural, political, and environmental issues, with interesting debates and questions pointing to whether globalization enhances or affects the quality of the environment. A recent study by Rehman et al. (2022) utilized the nonlinear ARDL technique with a global dataset spanning from 1985 to 2020 to examine the implications of globalization on CO_2 emissions. They found a negative connection between the pair, in both the short and long terms. With the aid of data from 2004 to 2019 for the top 10 CO_2 emitting economies in the OBOR region, Tsimisaraka et al. (2023) utilized the CS-ARDL estimation technique to assess the impacts of globalization on carbon dioxide emission. Their results showed an insignificant negative effect between the duos in the short run but revealed a significant negative relationship in the long term. Contrarily, another trending study by Wang et al. (2023) employed the AMG method using data for the top seven global carbon dioxide emitters from 1990 to 2019 to examine the effects of globalization on carbon emissions. The outcome revealed that CO_2 is positively induced by globalization. Awosusi et al. (2022) employed the MMQR technique to test the effect of economic globalization on carbon emission in top energy transition countries using the dataset from 1990 to 2021 and realized that the financial aspect of globalization has mitigation effects on CO_2 emissions across all quantiles while trade globalization only mitigates CO_2 within the lower quantiles. Using datasets for Turkey from 1971 to 2006, Dumrul et al. (2023) adopted the Fourier ARDL to examine the effects of economic globalization on carbon dioxide emissions. Their findings revealed that economic globalization positively affects carbon emissions evidenced by a unidirectional causal relationship running from this aspect of globalization to CO_2 emissions. By using the two-stage least square generalized method of moment (GMM) technique with a dataset from 1990 to 2016, Jahanger et al. (2022a) examined globalization's impacts on CO_2 for 78 developing economies within Africa, Asia, Latin America, and the Caribbean. Their study revealed mixed findings. The overall outcomes suggest that social globalization boasts carbon dioxide emissions across the studied regions, and political globalization augments CO_2 emissions in Latin America and the Caribbean but reduces CO_2 emissions in Africa and Asia. Moreover, the findings disclosed economic globalization curbs CO_2 emissions in Latin America and the Caribbean but heightens it in Africa and Asian economies. Another study by Mehmood (2022) explored the connection between economic globalization and environmental quality in South Asian economies using the CS-ARDL method with the aid of a dataset from 1980 to 2019. The results revealed a negative association between the variables. Ramzan et al. (2023) utilized the nonparametric causality-in-quantiles test to examine the linkage between information globalization and environmental quality in 10 foremost greenest countries from 1994Q1 to 2019Q4. The findings suggest that information globalization could be a great booster of economic growth by enhancing the efficiency of several important sectors like finance and industry but such improvements could be detrimental to the environment. A study by Baajike et al. (2022) applied the system GMM method alongside POLS, fixed effects, random effects, and the difference GMM to test the validity of the EKC hypothesis as it pertains to the link between trade openness (TO) and environmental quality in the ECOWAS sub-region from 2005 to 2018. The findings validate the EKC hypothesis by revealing that TO is harmful to the environment at the early stage of growth but may turn to boost it if quality institutions and market regulation mechanisms are put in place. However, several scholars claim that an important factor contributing to expansion of carbon footprint and the associated deforestation has been the growth in agribusinesses, large-scale farming, and forestry firms producing commodities for the global markets (Rudel et al. 2009). A study by Kalaycı and Hayaloğlu (2019) exploring relations between globalization and CO_2 emissions for NAFTA economies indicated globalization as a major cause of CO_2 emissions. Salahuddin et al. (2019) researched the link between globalization and the state of environmental quality in Sub-Saharan Africa (SSA) from 1984 to 2016 using the MG, AMG, CCEMG, and PMG but the results obtained are mixed and inconclusive. Acheampong et al. (2019) applied fixed and random effects valuation methods to assess the implications of economic globalization (trade and FDI) on environmental quality in SSA from 1980 to 2015 and found evidence of the EKC hypothesis. This implies that regulations control the economy and FDI to improve environmental quality. A similar study by Twerefou et al. (2019) employed the system GMM method to explore the association between globalization and environmental quality and sustainability in the case of SSA from 1990 to 2013. The findings revealed that globalization has detrimental effects on environmental quality and sustainability. Several strands of studies claiming globalization is detrimental to the environment are Majeed and Mazhar (2019), Chishti et al. (2020), Leal and Marques (2020), Baloch et al. (2021), Awan et al. (2020), Wen et al. (2021), and Sadiq and Wen (2022). Based on these reviews, we hypothesize that globalization increases CO_2emissions. This claim is supported by Le and Ozturk (2020).

H_2: Investment in agriculture enhances environmental quality

Agriculture and forest lands constitutes the two main land uses across the globe, and regional trends in these land uses are driven by economic development, socio-economic factors, and government policy (Nkonya et al. 2012). The EKC for land use change postulates that increase in agricultural, forestry, and related land uses stimulates economic growth, which affects the "ecological equilibrium" (Zhang et al. 2019; Ben Jebli and Ben Youssef 2017) but moderates forest extent when a certain threshold is attained (Nkonya et al. 2012). Most tropical countries are in the second phase of the EKC, yet, the EKC of forest extent and density has not been perceived especially in Sub-Saharan Africa (Congo Basin inclusive) partly due to limited research incorporating agriculture and CO_2 emissions and partly because of civilian conflicts, government policies, and the growing timber markets. Moreover, agricultural land use extent is reducing worldwide due to increase productivity rate but still increasing in Sub-Saharan Africa and Latin America because of insufficient investment in agriculture and weak market infrastructure. However, existing empirical studies on agriculture and carbon dioxide emissions are extensive with mixed outcomes. Jebli and Youssef (2017) utilized the OLS, FMOL, DOLS, and the Granger causality tests to explore the causal relations between agricultural value added and CO_2 emissions in North African economies from 1980 to 2011. The outcomes indicate that agriculture value added lessens CO_2 emissions. Another study by Waheed et al. (2018) also employed the ARDL technique to scrutinize the association between agricultural production and CO_2 emissions in Pakistan from 1990 to 2014. Their findings unveiled that agricultural production causes CO_2 emissions in Pakistan. In the case of E7 economies, Aydoğan and Vardar (2020b) assessed the impacts of agriculture value added on CO_2 emissions from 1990 to 2014 using OLS, DOLS, FMOLS, and Granger causality tests. The outcomes unveiled evidence of an inverted U-shaped EKC while agriculture value added causes CO_2 emissions in the top seven emerging economies. As part of the policy recommendation, the authors suggest that renewable energy use should be encouraged in the agricultural sector. Rehman et al. (2022) employed the ARDL, stepwise, and robust least square methods to examine the influence of agricultural variables (agricultural production) on carbon dioxide emissions in Bhutan from 1980 to 2020 and obtained mixed outcomes. More trending studies on agriculture-CO_2 emissions nexus led by Raihan Asif have produced mixed outcomes. For instance, Raihan (2023) scrutinized the association between agricultural productivity and CO_2 emissions in Thailand using the ARDL bound test and the DOLS methods with the aid of time series data from 1990 to 2020. Their findings showed a reduction in CO_2 emissions following an increase in agricultural productivity, thereby recommending the adoption of climate-smart agricultural practices and sustainable forest management as the way out. Another study by Raihan et al. (2023a) investigated the connection between agricultural productivity and CO_2 emissions using the DOLS, and Granger causality techniques from 1990 to 2019 and found that agricultural productivity reduces CO_2 emissions in Egypt. Raihan et al. (2023b) also scrutinized the relationship between agricultural productivity and CO_2 emissions in the Philippines using the ARDL bound test and the DOLS methods with the aid of time series data from 1990 to 2020. Their findings showed a reduction in CO_2 emissions following an increase in agricultural productivity, thereby recommending the adoption of climate-smart agricultural practices and sustainable forest management as the way out. In the case of Bangladesh from 1990 to 2019, Raihan et al. (2023c) examined the dynamic effects of agricultural value added, agricultural expansion, crop production, animal rearing, and fish production on GHG emissions using the DOLS technique. The findings revealed that the tested variables individually and collectively heighten GHG emissions, thus suggesting climate-smart agriculture as a remedy to curb GHG emissions in Bangladesh. Shah et al. (2023) studied the agricultural effects of CO_2 emission in the panel of ASEAN countries using the CCEMG and AMG techniques from 1990 to 2019 and realized that agriculture contributes to CO_2 emission. The authors recommended the use of renewable energy and cleaner technologies as well as eco-friendly laws to boost their pursuit of attaining the SDGs. Yahya and Lee (2023) investigated the role of agricultural production, agricultural trade (export) and agricultural export on GHG emissions in ninety countries from 1990 to 2019 using quantile regression techniques. The outcomes demonstrate that agricultural production and its export ameliorate CO_2 emissions while agricultural import aggravates CO_2 emissions, thus urging these countries to limit traditional farming and gravitate towards greener farming techniques. In the case of twenty-four OECD countries from 1990 to 2018, Selvanathan et al. (2023) formulated an advanced EKC frame to integrate the role of agriculture and other environmental determinants on CO2 emissions and applied the fixed effects regression on the individual economies and across the panel. Mixed outcomes were observed for single countries while agricultural production and forestland cover heightened CO_2 emissions in the panel. Zwane et al. (2023) assess the impacts of agricultural economic growth on agricultural-based CO_2 emissions in Africa from 1990 to 2019 using panel DOLS and FMOLS methods. The findings showed that agricultural economic growth has a detrimental effect on agricultural

CO_2 emissions in Africa thus; the authors suggest that renewable energy production and usage be encouraged to lessen agricultural CO_2 emissions. The summary of findings related to the impacts of agriculture and globalization on CO_2 emissions is displayed in Table 1. However, such research is rare in the tropical African rainforest. The Congo Basin has recently been considered a suitable environment for plantation agriculture, especially the production of native species like oil palms due to its fertile nature and suitable climatic conditions and also because land availability for oil palm production is constantly decreasing in Indonesia and Malaysia. Additionally, there are indications that the market prospects for exporting palm oil will be favourable and palm oil from the Congo Basin will have a huge

Table 1 Summary of literature on agriculture, globalization, and CO_2 emissions

Author(s) and year	Time scope	Study area	Methods	Outcome
Agriculture and CO_2 emissions				
Rehman et al. (2022)	1980–2020	Bhutan	ARDL, stepwise and robust least square	Mixed and inconclusive
Jebli and Youssef (2017)	1980–2011	North African economies	OLS, DOLS, FMOLS, and Granger causality tests	Agr reduces CO_2 emissions
Waheed et al. (2018)	1990–2014	Pakistan	ARDL	Agr causes CO_2 emissions
Aydoğan and Vardar (2020a)	1990–2014	7 foremost emerging economies	OLS, DOLS, FMOLS, and Granger causality tests	Agr causes CO_2 emissions
Raihan et al. (2023b)	1990–2020	Thailand	ARDL with bound test and DOLS	Agr reduces CO_2 emissions
Raihan et al. (2023a)	1990–2019	Egypt	DOLS and Granger causality tests	Agr reduces CO_2 emissions
Raihan et al. (2023b)	1990–2020	Philippines	ARDL with bound test and DOLS	Agr reduces CO_2 emissions
Raihan et al. (2023c)	1990–2019	Bangladesh	DOLS	Agr causes CO_2 emissions
Selvanathan et al. (2023)	1990–2019	24 OECD economies	Fixed effects regression technique	Agr causes CO_2 emissions
Yahya and Lee (2023)	1990–2019	90 economies	Quantile regression technique	Agr reduces CO_2 emissions
Zwane et al. (2023)	1990–2019	Africa	DOLS and FMOLS	Agr causes CO_2 emissions
Globalization and CO_2 emissions				
Jahanger et al. (2022)	1990 – 2016	78 developing economies	Two-stage least square GMM	mixed
Mehmood (2022)	1980 – 2019	South Asian economies	CS-ARDL	GLO reduces CO_2 emissions
Salahuddin et al. (2019)	1984 – 2016	Sub Saharan Africa (SSA)	MG, AMG, CCEMG, and PMG	Mixed & inconclusive
Acheampong et al. (2019)	1980 – 2015	SSA	Fixed effect and random effects	GLO reduces CO_2 emissions
Twerefou et al. (2019)	1990 – 2013	SSA	GMM	GLO is detrimental to Environmental quality and sustainability
Ramzan et al. (2023)	1994Q1 – 2019Q4	10 foremost greenest economies	Nonparametric causality-in-quantiles test	GLO enhances CO_2 emissions and Ecological Footprint
Baajike et al. (2022)	2005 – 2018	ECOWAS	System GMM, POLS, fixed effect, random effect, and difference GMM	GLO enhances CO_2 emissions
Rehman et al. (2022)	1985 – 2020	World	NARDL	GLO reduces CO_2 emissions
Tsimisaraka et al. (2023)	2004 – 2019	10 foremost CO_2 emitters	CS-ARDL	Inconclusive and mixed
Wang et al. (2022)	1990 – 2019	7 foremost CO_2 emitters	AMG	GLO enhances CO_2 emissions
Awosusi et al. (2022)	1990 – 2021	Top energy transition economies	MMQR	Inconclusive and mixed
Dumrul et al. (2023)	1971 – 2006	Turkey	Fourier ARDL	GLO enhances CO_2 emissions

Fourier ARDL Fourier autoregressive distributed lag, *MMQR* method of moments quantile regression, *AMG* augmented mean group, *CS-ARDL* cross-sectional autoregressive distributed lag, *NARDL* nonlinear autoregressive distributed lag, *GMM* generalized method of moments, *POLS* pooled ordinary least squares, *MG* mean group, *PMG* pooled mean group, *CCEMG* common correlated effects mean group, *OLS* ordinary least squares, *DOLS* dynamic OLS, *FMOLS* fully modified OLS, *ECOWAS* economic community of West African states, *SSA* Sub-Saharan Africa demand domestically and at the sub-national levels (Hoyle and Levang 2012). Therefore, countries across the basin have increased investment in agriculture as a major engine for economic growth (Megevand and Mosnier 2013). This has led to rapid increases in planting oil palm and more trees. In addition, country-based studies conducted within the Congo Basin suggest that the growing of tree crops is an effective agro-forestry technique that will help in abating the nefarious effect of climate change (Awazi et al. 2021, 2019). Based on this, we hypothesize that investments in agriculture and improvements in agricultural techniques reduce CO_2 emissions.

$H_{3:}$ Urbanization is detrimental to environmental quality

The Malthusian population theory claims, with too many people, more resources are required. When this happens to urban communities, the demand for resources will result in severe encroachments on available city resources in many ways. In cities, more lands for housing are needed with rising population, leading to more clearance for both construction activity and subsistence agriculture. Across the Congo Basin, cities surrounded by forest resources are currently witnessing halos of degraded forest and savanna-like ecosystems in Kinshasa, Yaounde and Libreville. In many ways, the degradation is the direct results of lack of basic human necessities in urban areas, and people are forced to find their livelihoods through resources destruction. Peri-urban areas begin to witness serious encroachment with the growth of urban sprawl, which tend to upset the delicate balance between populations and the environment. Several experts have claimed urban poverty as dialectic with poverty being the major cause of degradation. Animals becomes victims for food requirements, and water is consequently polluted, especially in Kinshasa which has population of over 5 million (Redford 1995; Nkongho et al. 2014). Available studies indicate, in Congo Republic, more than 80% of the populations rely on wood fuel energy sourcing, while charcoal production has expanded in Cameroon (Megevand and Mosnier 2013). Contrary to popular claims, according to a study by Liang et al. (2019), the effects of urbanization on CO_2 emissions are unclear. However, several studies confirm that urbanization is a massive anthropogenic factor disrupting the carbon cycle and destroying available ecosystems (Ahmed et al. 2020; Buyantuyev and Wu 2009). Based on this review, this study hypothesizes that increasing urbanization is detrimental to the environment. This claim is supported by Sun et al. (2022) for MENA countries.

H_4: Biomass energy use reduces carbon dioxide emissions

Biomass energy (BE) is an energy type from several non-fossil biological materials, including soybean, corn kernel, Miscanthus, switchgrass, and maize stover. Studies have shown that biomass energy serves several purposes including cooking, heating, and industrial activity (Rosillo-Calle 2012). It is also a renewable energy source which can produce liquid fuel (Wang et al. 2020); and helps communities reduce overreliance on fossil fuels, and in the process lower greenhouse gas emissions. Empirical studies by Sarwar (2019) for the case of China indicated that biomass energy reduces urban CO_2 emissions. Similarly, Liu et al. (2022) found that biomass energy usage reduces carbon dioxide emissions in Brazil, Canada, Thailand, China, Italy, India, Germany, USA, UK, and Japan between 1991 and 2018. This review helps us to hypothesize that increasing biomass energy consumption reduces environmental degradation. This assumption is supported by Yasmeen et al. (2022).

H_5: A steady rise in economic growth results in an increase in CO_2E.

Historically, beginning from the pioneering study of Grossman and Krueger (1991), the relationship between income and the environment has been studied widely with findings indicating that increasing economic growth generates CO_2E (You et al. 2022; Lee et al. 2021; Abbasi et al. 2021; Yang et al. 2021; Kirikkaleli 2020). Such findings have been validated by numerous scholars including Adedoyin et al. (2020) and Addai et al. (2022). Given these findings, this study hypothesizes that rising economic growth increases CO_2E. This claim is supported by Kirikkaleli et al. (2022).

Based on the assessment of past studies, the following gaps are evident. (i) While the impacts of globalization, agricultural land use change, biomass energy use, urbanization, economic growth, and CO_2 emissions have been widely assessed across different countries and regions of the world, little or no consideration has been given to their association, in tropical African rainforest. The few studies conducted in the context of Sub-Saharan Africa displayed a high degree of variability in terms of their findings thus, calling for further research. (ii) The body of literature related to agriculture and CO_2 emissions is mixed and unsettled. Most of the assessments are country-based and are conducted using varied empirical approaches. In the case of SSA, such studies are rare and the few existing ones have yielded mixed outcomes. However, none of such studies has investigated the case of the Congo Basin, thus indication the significance of our study. (iii) In terms of policy, countries in the Congo Basin have diverse agricultural policy goals. Thus, there is the need for an integrated agricultural policy framework that aligns with the achievement of the SDGs for the entire enclave. (iv) Globalization has proven to be a vital component in determining the future of our global environment. Yet, most studies in the literature have focused on using just the economic aspect of globalization to determine the state of the environment, leaving out the social and political aspects. To fill this gap, we utilized the dataset that combines all aspects of globalization for more inclusive results. Moreover, to the best of our knowledge, no attention has been accorded to the role of globalization on CO_2 emissions in the Congo Basin thus, validating the relevance of this study. (v) From this summary of the literature, it can be observed that regardless of the variable used as proxy for environmental quality, there is no consensus on the EKC framework because they produce differing outcomes. This could be because of variations in the time scope of the studies, economies under consideration, control variables, and the empirical strategy or econometric methods applied. (vi) Most studies usually separate the EKC from the STIRPAT frameworks, but testing the EKC hypothesis within the STIRPAT framework is quite rare. Energy consumption is essential in validating the EKC and the STIRPAT frameworks, thus eliminating it from these frameworks may produce flawed outcomes. Based on these discoveries, the deficiency of research with respect to agricultural land use change and globalization on CO_2E is not the only drive of this study. Combining and assessing the role of biomass energy consumption, economic growth, and urbanization constitute an additional motivation given that thorough research incorporating CO_2E is essential for the Congo Basin and the tropical world at large. It equally employed advanced econometric methods like the CIPS/CADF, Westerlund cointegration, and ARDL/PMG estimators which are validated in the previous literature as yielding robust outcomes (Işık 2013).

Methodology

Data

The current study assesses the dynamic impacts of agricultural land use change and globalization on environmental quality in the Congo Basin. To achieve this aim, the study controlled for economic growth, biomass energy consumption, and urbanization noted in literature to influence environmental quality. Data was collected on (i) CO_2 emissions (CO_2) as proxy for environmental quality and as dependent variable. Carbon dioxide (CO_2) is a gas generated from living organisms as they breathe and through carbon burning. It is measured in metric tons (tCO_2) (Krey et al. 2014), and it is sourced from Our World in Data (2023). For its determinants, data was collected on (ii) agriculture, forestry, and fishing value added (AFFVA) in constant 2015 US$ from the World Bank (2023) as proxy for agricultural land use change (ALUC). Per the International Standard Industrial Classification (ISIC), AFFVA represents the net yield of a primary sector (crop production, forestry, fishing, hunting, and animal rearing) after summing up the gross output and taking out intermediary inputs. These activities are debatably the key drivers of local landscape transformation. Based on this notion, agricultural land use change denotes the transformation of the natural landscape by humans for economic reasons (commercial or consumption) through farming, animal rearing and related activities (Alexander et al. 2015). (iii) Globalization (GLO) data was obtained from KOF Swiss Economic Institute (2022); globalization describes rising engagement and reliance of economies worldwide on trans-border commerce, technology, investments flows, information, and migration (Gancia et al. 2022). It is quantified by taking into consideration the number of treaties signed with the external world, participation in UN Security Council assignments, and number of embassies, belonging to a world governing body. Besides, it involves foreign direct investments, indicators on capital flows, the economic activity of multinational organizations, international commerce, and global technological transfer. Data were also obtained from the World Bank (2023) on (iv) GDP per capita GDP, in constant 2015US$) as proxy for economic growth. Economic growth describes an increase in both quality and quantity of services and goods fabricated and consumed within an economy (Jones and Liu 2022). (v) Biomass energy consumption (BIO) was sourced from the International Resource Panel (2023). Biomass energy is produced from diverse organic matter including but not limited to urban agricultural waste, plants, and trees and can be put to multiple uses such as heating, electricity generation, and transport fuels (Güney and Kantar 2020). It is commonly quantified in grams per meter squared (g/m^2). It can also be measured in kilogram per square meter and pound per square foot based on the jurisdiction and may easily be transformed into carbon storage. (vi) Urban population (% of total population) was sourced from the World Bank (2023) as proxy for urbanization. The data for this study (Table 2) was collected on four countries in the Congo Basin (i.e., Cameroon, The Republic of Congo, Gabon, and Democratic Republic of Congo) from 1980 to 2018. Variables are then converted into natural logarithms to minimize scattering, smooth the data, and reduce autocorrelation and heteroscedasticity issues. Figure 3 illustrates the methodological flow diagram.

Framework adoption and model description

The role of agriculture, globalization, biomass energy, urbanization, economic growth, and environmental quality has been a key policy subject for several decades. The Congo Basin has a high growth prospect propelled by fossil fuel-based initiatives, as countries in this enclave are powered by a huge natural resource potential (forest, petroleum and diamond). Based on this notion, these countries have the ability to drive economic expansion due to the cross-border mobility of human capital and natural resources, though with adverse environmental impacts. In theory, the economic aspect of globalization creates income through natural resource rents for industrial development. Additionally, based on the pollution haven hypothesis, the global

Table 2 Parameters and unit of measure

Code	Description	Unit of measure	Source
LCO_2	Carbon dioxide	CO_2 emissions (tones per capita)	OWD
LGDP	Economic growth	GDP per capita (constant 2015 $)	WDI
LBIO	biomass energy usage	Tones per capita	IRP
LALUC	Agriculture, forestry, and fishing	Agriculture, forestry, and fishing, value added (constant 2015 US$)	WDI
LGLO	Globalization	Globalization index (economic, social and political aspects)	KOF
LURBN	Urbanization	Urban population (% of total population)	WDI

Countries considered in this study are Cameroon, the Republic of Congo, Gabon, and Democratic Republic of Congo

OWD Our World in Data, *WDI* World Development Indicators, *IRP* International Resource Panel, *KOF* Swiss Economic Institute

interconnection between countries of the Congo Basin and the rest of the world has led to the establishment of logging companies and extractive firms in this enclave, which are often associated with unsound environmental practices.

Besides these, the rapid population growth and urbanization among countries and major cities in this region as well as the fiery desire to satisfy their food needs has led to the cutting of forests for agricultural expansion, which is often associated with GHG emissions. Furthermore, the ongoing country-based initiatives to become emerging economies have led to a steady rise in pollution in this region thus, necessitating a holistic approach by governments and policymakers to initiate changes in the energy basket of these economies. Industrial operations rely heavily on either fossil fuel or renewable energy to enhance economic growth, improve standards of living, and satisfy social needs. Nevertheless, the energy production mechanism matters for global policy decision-making and environmental quality. Therefore, policy action is required to deal with possible harmful environmental outcomes.

Therefore, to address environmental quality concerns, renewable energy initiatives should be encouraged especially by employing external developmental forces into the prevailing economic development path. These could be achieved by donating foreign support to industries through external inflows like foreign debt or aid, and foreign direct investments. These provisions have the propensity to equip nations with trending and innovative renewable energy technologies that can boost environmental quality. Improvement in the financial system propelled by clean energy production and usage has the potential to achieve sustainable economic growth while enhancing environmental quality simultaneously. Based on this theoretical foundation, the EKC framework best explains this transformative influence, given that the scale and composite effects of economic growth depicted as level and quadratic notations denote the combined transformative effect of this growth path.

Another important theoretical framework widely used in assessing the environmental impacts of human activities is the stochastic (ST) impacts (I) by regression (R) on population (P), affluence (A), and technology (T), famously referred to as STIRPAT. In this study, the dependent variable and all the controls are captured within the STIRPAT framework: CO_2 emission captures environmental impacts (I), urbanization denotes population (P), economic growth represents affluence (A), and biomass energy is renewable energy, which can be obtained through industrial processes as a result of advancements in technology (T). The core explanatory variables in this study, agricultural land use change, and globalization are not found within STIRPAT. To incorporate these core determinants of the study into the framework, an extended STIRPAT has been utilized. One noticeable feature of the STIRPAT framework lies in its flexibility as it allows the EKC hypothesis to be tested within its framework. Nonetheless, investigating the association between these variables demands that we align our assessment based on the sustainable development goals' targets of

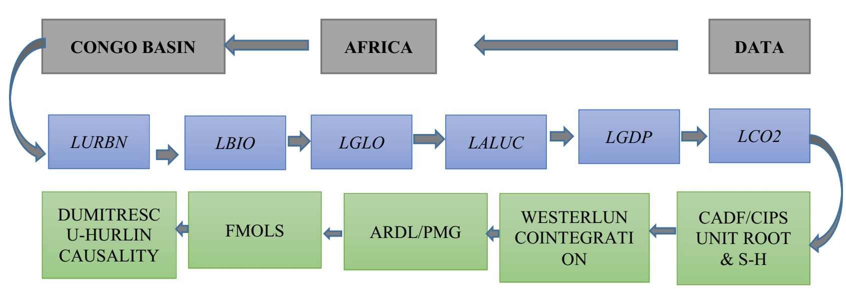

Fig. 3 Methodological flow diagram

countries in the Congo Basin, and therefore, this connection need to be expressed mathematically

$$LCO2_{it} = f\left(LGDP_{it}, LALUC_{it}, LGLO_{it}, LBIO_{it}LURBN_{it}\right) \tag{1}$$

where LCO_2 is log of carbon emissions as proxy for environmental quality, $LGDP$ is log of GDP growth, $LALUC$ is log of agricultural land use change ($LALUC$), $LGLO$ is log of globalization, $LBIO$ is log of biomass energy consumption, and $LURBN$ is log of urbanization.

The study next uses a single multivariate model to investigate the linkages amongst the concerned parameters. The specified log-linear specifications for the empirical model is:

$$\begin{aligned} LCO_{2it} = & \beta_0 + \beta_1 LGDP_{it} + \beta_2 LALUC_{it} \\ & + \beta_3 LGLO_{it} + \beta_4 LBIO_{it} \\ & + \beta_5 LURBN_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

where β_0 is constant; i is number of selected panel (1–4); t is timeframe (1980–2018); $\beta_{1,}$ β_2, β_3, β_4, and β_5 are coefficients of GDP growth, agricultural land use change, globalization, biomass energy consumption, and urbanization respectively; e_{it} is the error term.

Cross-sectional dependence (CSD) and slope homogeneity (S-H) tests

The growing global economic impediments have brought nations into a politically and economically concerted space in order to function properly and to speed up their growth process. As the global dependency amongst countries increase, CSD issues arises as a key property in panel models owing to the effects of unidentified collective tremors in residuals and variables (Chudik et al. 2011). Therefore, to avoid unbiased estimations and ensure warranty in the estimation outcome, it is vital to assess the cross-sectional association in panels. Not only does this helps to select appropriate unit root and co-integration tests, it equally increases reliability and limits the chances of producing biased outcomes (Baltagi et al. 2016). This study scanned for CSD in the Congo Basin panel using four specific tests: Breusch-Pegan LM, Peseran scaled LM, biased-corrected scaled LM, and Peseran CD tests (Pesaran 2015) as expressed in Eq. (3). In addition, verifying for slope heterogeneity coefficient is vital, without which the assumptions of slope coefficient of homogeneity may produce deceptive valuation outcomes. In conformity to this assumption, the study utilized the Pesaran and Yamagata (2008) and the Blomquist and Westerlund (2013) to assess for S-H in the cross-sectional data (see Eqs. 4–7). However, both techniques are superior forms of Swamy (1970) as their robustness vary across the ladder. The presence of S-H indicates failure to reject the null hypothesis.

$$\mathrm{CSD}_{TM} \frac{TN(N-1)^{1/2}}{2} \overline{\rho}_N \tag{3}$$

Here, the parameters of pairwise correlation are represented by $\overline{\rho}_N$, N and T represents cross-sectional units in relation to numbers and time period, respectively.

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\overline{S} - k}{\sqrt{2k}}\right) \sim X_K^2 \tag{4}$$

$$\tilde{\Delta}_{\mathrm{adj}} = \sqrt{N}\left(\frac{N^{-1}\overline{S} - k}{v(T,k)}\right) \sim N(0,1) \tag{5}$$

$$\Delta_{HAC} = \sqrt{N}\left(\frac{N^{-1}S_{HAC} - k}{\sqrt{2k}}\right) \sim X_K^2 \tag{6}$$

$$\left(\Delta_{HAC}\right)_{\mathrm{adj}} \triangleq \sqrt{N}\left(\frac{N^{-1}S_{HAC} - k}{v(T,k)}\right) \sim N(0,1) \tag{7}$$

S represents Swamy test statistic, N denotes number of cross section units, k represents the independent variables**,** while Δ_{HAC} and $(\Delta_{HAC})_{\mathrm{adj}}$ stands for large and small sample size, respectively, with heteroscedasticity and autocorrelation consistent, and $(\Delta_{HAC})_{\mathrm{adj}}$ is the mean-variance bias-adjusted version of Δ_{HAC}.

Stationarity test

The stationarity or unit root assessment helps to unveil the state and integration order of variables. Its outcomes serves as prerequisite to choosing appropriate co-integration and empirical model for estimating the relationship between variables. The normal panel stationarity measurements established under the assumption of homogeneity and cross-sectional independence usually experience size bias and control properties, resulting to unfair and deceptive outcomes (Phillips and Sul 2003). In this regard, two exclusive second generation stationarity test approaches proposed by Pesaran (2007) are utilized in this study to detect the integration order of the concerned variables as depicted in Eqs. (8) and (9). As opposed to the previous panel unit root tests, Pesaran (2007) reinforced the ordinary augmented Dickey-Fuller (ADF) regressions with the cross-sectional averages of the dependent and predictive indicator lag values and first differenced of all cross-sectional units by asymptotically scrutinizing the effects of CSD and unseen common dynamics.

$$\Delta Y_{i,t} = \gamma_i + \gamma_i Y_{i,t-1} + \gamma_i \overline{X}_{t-1} + \sum\nolimits_{l=0}^{P} \gamma_{il} \Delta \overline{Y_{t-1}} + \sum\nolimits_{l=1}^{p} \gamma_{il} \Delta Y_{i,t-l} + \varepsilon_{it} \tag{8}$$

The CIPS test is derived from Eq. (8) as follows

$$\hat{CIPS} = \frac{1}{N}\sum_{i=1}^{n} CADF_i \tag{9}$$

The average lagged of the cross section and the first differenced of its averages are is denoted by $\overline{Y}_{t-1}$ and $\Delta\overline{Y_{t-1}}$, respectively.

Panel co-integration test

The unit root test results helps to determine whether co-integration test should be performed prior to estimating the long-run association between variables of interest. In case variables are stationary at level, the ordinary least square (OLS) methods is recommended to estimate the long-run associations between variables; otherwise (when stationary at first difference), the OLS methods become ineffective to check for co-integration among variables. When it is the case, co-integration methods like the McCoskey and Kao (1998) and Pedroni (2004) can be utilized, although they are less robust in detecting co-integration when there is CSD and slope heterogeneity among variables, as they may produce flawed results. This study utilized the Westerlund (2007) co-integration test, which is innovative and more robust to test for long-term links among variables in presence of CSD and S-H. Equation (10) depicts the co-integration test.

$$\alpha i(L)\Delta y_{it} = y2_{it} + \beta_i\left(y_{it} - 1 - \acute{\alpha}_i x_{it}\right) + \lambda_i(L)v_{it} + \eta_i \tag{10}$$

Where

$$\delta_{1i} = \beta_i(1)\hat{\vartheta}_{21} - \beta_i\lambda_{1i} + \beta_i\hat{\vartheta}2_i \text{ and } y2_i = -\beta_i\lambda 2_i \tag{11}$$

The co-integration test statistics according to Westerlund are expressed in Eqs. (12), (13), (14), and (15)

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\acute{a}_i}{SE\left(\acute{a}_i\right)}, \tag{12}$$

$$G_a = \frac{1}{N}\sum_{i-1}^{N}\frac{T_{\acute{a}_i}}{\acute{a}_i(1)}, \tag{13}$$

$$P_T = \frac{\acute{a}}{SE\left(\acute{a}\right)}, \tag{14}$$

$$P_a = T_{\acute{a}} \tag{15}$$

Here, group statistics are denoted by G_t and G_a, whereas panel statistics are represented by P_T and P_a. The null hypothesis for this statistics stands for no co-integration.

Long-run estimation using ARDL/PMG estimator

After detecting the integration order of the concerned variables using stationarity tests and realizing a long-run association between them from the co-integration test, it is primordial to select an appropriate long-run estimation approach that can both handle the behavior of data and produce reliable results. The studied variables are integrated both at level; $I(0)$ and at first differenced; $I(1)$ which are harmonious with the autoregressive distributive lag/pooled mean group (ARDL/PMG) empirical model developed by Pesaran et al. (1999). The merits of ARDL/PMG emanates from the fact that it supports short-run heterogeneity in panels and restricts it in the long run in favor of homogeneity. It also resolve issues related with serial correlation and endogeneity. The study follows the ARDL/PMG model as expressed in Eq. (16).

$$\begin{aligned}\Delta LCO_{2i,t} =& \beta_0 + \sum_{j=1}^{p-1}\beta_{1i}\Delta LCO_{2i,t-1} + \sum_{j=0}^{q-1}\beta_{1i}\Delta LGDP_{i,t-1}\\ &+ \sum_{j=0}^{q-1}\beta_{2i}\Delta LALUC_{i,t-1} + \sum_{j=0}^{q-1}\beta_{3i}\Delta LGLO_{i,t-1}\\ &+ \sum_{j=0}^{q-1}\beta_{4i}\Delta LBIO_{i,t-1} + \sum_{j=0}^{q-1}\beta_{5i}\Delta LURBN_{i,t-1}\\ &+ \delta_1 LCO_{2i,t-1} + \delta_2 LGDP_{i,t-1}\\ &+ \delta_3 LALUC_{i,t-1} + \delta_4 LGLO_{i,t-1}\\ &+ \delta_5 LBIO_{i,t-1} + \delta_6 LURBN_{i,t-1} + \delta_{i,t-1} + ECT_{i,t-1} + \varepsilon_{it}\end{aligned} \tag{16}$$

Notes that β and δ represent short- and long-term parameters; ε_{it} denotes residuals of country i at time t, while Δ is the difference operator after rendering the data stationary; $ECT_{i,\,t-1}$ represents the error correction term, which defines the dynamic stability of the model. The model stability is evident when the ECT value has a negative sign and is significant; thus, instability in the short-term is automatically adjusted in the long run; p and q represent the lags of the dependent variable (p) and regressors (q). For the model specification process, the study proceeded with automatic selection, using maximum lags 2 and 3 for the dependent variable and predictors, respectively, at constant (level), while the Akaike information criterion (AIC) option was selected.

Fully modified ordinary least square (FMOLS)

The FMOLS long-run estimators is developed using the ordinary least square. Authored by Pedroni (2001), the FMOLS is more robust than the OLS because it corrects for serial correlation and endogeneity issues in data analysis.

Table 3 Data description

	LCO2	LGDP	LBIO	LALUC	LGLO	LURBN
Mean	−0.308011	3.277278	7.186620	9.132133	1.616900	6.558622
Median	−0.225249	3.258190	7.165446	9.085666	1.643663	6.508030
Maximum	0.960613	3.994291	8.175056	9.870613	1.734309	7.572601
Minimum	−1.787474	2.523767	6.189962	8.472243	1.407576	5.598982
Std. Dev.	0.736149	0.437299	0.656845	0.495756	0.080423	0.525531
Skewness	−0.331930	0.132185	0.021809	0.073092	−0.579276	0.113077
Kurtosis	2.209827	2.054522	1.341553	1.238718	2.437618	1.864476
Jarque-Bera	6.923047	6.264832	17.89028	20.30265	10.78037	8.713648
Probability	0.031382	0.043612	0.000130	0.000039	0.004561	0.012819
Sum	−48.04970	511.2554	1121.113	1424.613	252.2364	1023.145
Sum Sq. Dev.	83.99696	29.64074	66.87394	38.09498	1.002510	42.80841
Observations	156	156	156	156	156	156

In this regard, FMOLS is utilized in this study purposely to confirm the strength of the ARDL/PMG.

Empirical outcomes and discussion

Summary statistic

It is essential to have a glimpse understanding of data prior to continuing with the estimation. In this regard, the summary data statistics are presented in Table 3.

From Table 2, LALUC recorded the highest mean (9.132133), which ranges from 8.472243 to 9.870613. This is followed closely by LBIO (7.186620), which ranges from 6.189962 to 8.175056, LURBN (6.558622) which ranges from 5.598982 to 7.572601, LGDP (3.277278) which ranges from 2.523767 to 3.994291, LGLO (1.616900) which ranges from 1.407576 to 1.734309, and LCO_2 (−0.308011) which ranges from −1.787474 to 0.960613. The skewness values show that LCO_2, LGDP, and LURBN are positively skewed, while LGLO is negatively skewed. Moreover, LBIO and LAULC are symmetric around the sampled mean. The kurtosis values indicates that LGDP, LBIO, LALUC, LGLO, and LURBN are platykurtic (with lower values than the sampled mean), while LCO_2 is leptokurtic (with a higher value than the sampled mean). The Jarque-Bera values disclose that not all the variables adhere to normal distribution as evident by the probability values that are far below 0.1. These Jarque-Bera results implied that using ordinary least square estimation procedure would produce deceptive outcomes. Therefore, we utilized the CIPS, CADF, bootstrapped co-integration, and PMG/ARDL techniques to waive estimation errors that may result when assessing the interrelationships between the selected variables.

Cross-sectional dependence (CSD) and slope homogeneity outcomes

The study further scanned for cross sectional dependence (CSD) using the Breusch-Pegan LM, Peseran scaled LM, biased-corrected scaled LM, and Peseran CD tests. Adebayo et al. (2022b) suggest that cross-sectional dependence test may be utilized to assess the dependence of cross-sections within a panel. Hence, if disregarded CSD can disrupt the precision of estimated values of variable, which can potentially, lessen the efficacy of panel data. The outcome in Table 4 discards the null hypothesis and validates its alternative that suggests the availability of CSD in the panel. This outcome implies that Congo Basin countries are socio-economically interdependent on each other and any disruption in one country's essential variables will more or less extend to the other country due to the spillover effects. Furthermore, the Pesaran and Yamagata (2008) and Blomquist and Westerlund (2013) S-H tests are assessed in the panel (see Table 5), and the outcomes indicates that variable slopes

Table 4 CSD estimates

Test	LCO2	LGDP	LBIO	LALUC	LGLO	LURBN
Breusch-Pagan LM	57.30593*	63.22192*	202.6019*	183.0161*	177.7869*	233.2458*
Pesaran scaled LM	14.81075*	16.51855*	56.75407*	51.10014*	49.59060*	65.60020*
Bias-corrected scaled LM	14.75811*	16.46591*	56.70144*	51.04751*	49.53797*	65.54757*
Pesaran CD	−0.264999	7.171381*	14.22580*	13.52210*	13.32351*	15.27238*

*$p < 0.01$

Table 5 Slope homogeneity (S-H) tests

Pesaran and Yamagata (2008)			Blomquist and Westerlund (2013)		
Tests	Delta value	*P*-value	Tests	Delta value	*P*-value
	7.505*	0.000		1.754***	0.079
adj.	8.285*	0.000	adj.hac	1.936**	0.053

*, **, and *** represent $p < 0.01$, $p < 0.05$, and $p < 0.10$, respectively

are heterogeneous, thus rejecting the null and validating the alternative hypothesis (as evident by delta values in Table 5). This indicates that a change in the socio-economic structure of one country can potentially affect the socio-economic structure of the other. Thus, slope homogeneity in panel data requires attention.

Unit root test

The unit root features of the variable are further assessed in this study using the CADF and the CIPS stationarity tests initiated by Pesaran (2007). Both are advanced tests and are utilized in this research because the panel exhibits CSD and slope heterogeneity (S-H).

Table 6 depict the outcomes of the CIPS and CADF. From Table 6, the series exhibits a mixed order of integration. These outcomes set the pace for the next phase, which looks at the interrelationship between variables with respect to con-integration, prior to foretelling long-run coefficients.

Co-integration estimates

Based on the stationarity outcomes, the study takes a step ahead to assess the long-term connection between LCO_2 and its predictors. In doing so, the Westerlund (2007) bootstrapped co-integration test is applied as opposed to McCoskey and Kao (1998) or Pedroni (2004) which assumes common-factor limitation on co-integration tests. Shahbaz et al. (2019) reiterates that it crucial to safeguard power-based co-integration of residuals in structural dynamics. With the elimination of this constraint, short- and long-run amendment procedures no longer need to be the same, given that we can minimize the misleading effects of CSD process by utilizing Westerlund (2007) co-integration test.

Table 6 CIPS and CADF unit root tests

Variables	CIPS		CADF	
	I(0)	*I*(1)	*I*(0)	*I*(1)
LCO2	−2.805*	−5.328*	−2.864*	−5.034*
LGDP	−2.809 *	−4.216 *	−2.676 *	−3.098 *
LBIO	−2.371**	−5.805*	−2.176	−4.897*
LALUC	−1.461	−5.003*	−1.786	−3.750*
LGLO	−2.657*	−5.485*	−3.003*	−4.107*
LURBN	−2.830*	−1.830	−2.739*	−3.063*

* and ** represent $p < 0.01$ and $p < 0.05$, respectively

Table 7 Westerlund (2007) bootstrapped co-integration estimates

Statistic	Value	*Z*-value	*p*-value	Robust *p*-value
Gt	−4.397	−3.003	0.001	0.000
Ga	−1.079	3.947	1.000	1.000
Pt	−7.910	−2.348	0.009	0.000
Pa	−0.877	3.282	1.000	1.000

As depicted in Table 7, the outcomes indicate that there exist a long-term connection between LCO_2 emission and its regressors. In this regard, the null hypothesis of "no co-integration" amid CSD, S-H, and serial correlation is declined given that Gt (−4.397, $p < 0.000$) and Pt (−7.910, $p < 0.000$) are significant at 1%. This is proof of a co-integrating relationship between CO_2it, *LGDPit*, *LBIOit*, *ALULCit*, *LGLOit*, and *LURBNit*. Moreover, the ECM for our model is computed as$\frac{P_a}{T} = \frac{-0.877}{38} = -0.023$. Thus, uncertainty in the short-term will be rectified at 2.3% in the long term on yearly bases. The affirmation of co-integration between variables implies that the determinants of CO_2 emissions can then be investigated.

Long-term equilibrium ARDL/PMG estimates

After confirming co-integration amongst the series, the long-run connection between LCO_2 and its determinant are further estimated. In doing this, the study applied the autoregressive distributive lag/pooled mean group (ARDL/PMG) techniques (Table 8).

The long-term equilibrium ARDL/PMG estimates show that LGDP exerts positive and significant effects on LCO_2. In accordance with Table 8, a unit rise in LGDP will cause LCO_2 to increase by 1.514259, in the Congo Basin, keeping

Table 8 Autoregressive distributive lag/pooled mean group (ARDL/PMG) estimates

Variable	Coefficient	Std. error	*t*-Statistic	Prob.*
	Long run equation			
LGDP	1.514259*	0.107945	14.02810	0.0000
LBIO	−0.465773*	0.096869	−4.808262	0.0000
LALUC	−0.528912*	0.123921	−4.268123	0.0001
LGLO	0.749885**	0.387508	1.935147	0.0567
LURBN	−1.713214*	0.494681	−3.463272	0.0009
COINTEQ01	−0.733404*	0.294313	−2.491921	0.0149
C	8.864669	3.356205	2.641278	0.0100

* and ** represent $p < 0.01$ and $p < 0.05$, respectively

other parameters constant. This outcome aligns with hypothesis 5 (H_5) which supposed that a steady rise in economic growth leads to increase in CO_2 emissions. These results are in agreement with the EKC hypothesis, implying that after attaining a certain threshold in income, GDP will boast environmental quality in the Congo Basin. These outcomes coincides with Malik (2021) for Turkey; Kirikkaleli (2020) for China, Wasti and Zaidi (2020) for Kuwait; Aydoğan and Vardar (2020b) for E7 countries; and Shahbaz et al. (2019) for Middle East and North African countries. Congo Basin countries are currently under the World Bank category of lower income and lower middle-income countries and are highly driven by future prospects for emergence. For instance, Cameroon, the Republic of Congo, Gabon, and the Democratic Republic of Congo (DRC) are striving for emergence and economic expansion by the years 2035, 2030, 2035, and 2030, respectively, based on their future poverty alleviation strategic documents. However, these countries do not have a clearly defined environmentally benign policy, and therefore, planning for such emergence without a holistic environmentally responsive strategy may be futile. Therefore, attaining such emergence will require policies aimed at reducing the negative impacts of growth on the environment by following a growth path that is powered by renewable energy consumption and not fossil fuel driven.

Contrarily, the long-run equilibrium connection between LBIO and LCO_2 recoded a negative and significant coefficient when other variables are kept constant. In harmony with Table 8, this signifies that a unit increase in LBIO will lead to a comparable decrease in LCO_2 by -0.465773. This outcome endorses hypothesis 4 (H_4) which states that biomass energy use reduces carbon dioxide emissions in the Congo Basin. This finding concords with Sulaiman and Abdul-Rahim (2020) for EU countries, Sulaiman et al. (2020) for African economies, Dogan and Inglesi-Lotz (2017) for biomass producing countries, and Shahbaz et al. (2019) for Middle East and North African countries. However, the findings in this study opposed those of Gao and Zhang (2021) for developing Asian economies and Solarin et al. (2018) for 80 developed and developing countries. Analysis channeled to the Forest Carbon Partnership Facility vis-à-vis national REDD+ readiness proposals and REDD+ strategies indicates that committed environmental friendly actions are ongoing across the Congo Basin. Notable examples include the certification of agricultural plantations, climate-smart agriculture, implementation of VPA-FLEDT, the creation of wood fuel energy plantations, and energy efficiency campaigns. As far as these measures aligns with the principles of sustainable growth, their implementation may seems questionable due to lack of institutional collaboration among the countries. For countries in this enclave to achieve SDGs 7, 13, and 15, new and holistic investments in modern bioenergy, production is essential given that biomass is freely available in this region and its combustion is beneficial to the environment. Therefore, investment in research and development towards bioenergy and other cleaner sources of energy is a great starting point for economies across the Congo Basin.

Furthermore, long-term equilibrium ARDL/PMG co-integrating estimates indicates that the coefficient for LALUC (Table 8) is negative and significant, implying that LALUC exerts negative effects on LCO_2. These results signify that LCO_2 reduces by −0.528912 following a unit increase in LALUC. This result agrees with hypothesis 2 (H_2) which suggests that investment in agriculture enhances environmental quality in the Congo Basin. This finding is in similar agreement with Jebli and Youssef (2017) for North African countries and Rafiq et al. (2016) for high-, medium-, and low-income nations but contrary to the findings of Jebli and Youssef (2015) for Tunisia and Waheed et al. (2018) for Pakistan. Contextually, agriculture in this region is largely labor intensive and dominated by smallholder farmers who depend principally on rudimentary materials to realize yields. Hence, the agricultural sector may be less polluting than other sectors like transport and manufacturing. Over the years, governments across the region have encouraged policies aimed at expanding the use of synthetic fertilizers, hybrid seeds, and pesticides to boost yields and enhance smallholder farmers' resilience to climate variability and change. This may seem helpful at first sight, but in the long term, synthetic fertilizer may diminish soil fertility in the presence of chemical nitrogen, which has the potential to stimulate the excessive growth of microorganisms' growth, but over time depletes organic matter in the soil. It is therefore incumbent to embrace policies that can accelerate agricultural productivity while preserving the natural environment. This includes among others the growing of food crops amidst tree (cash) crops. This practice aligns with the empirical findings of Awazi et al. (2019) who suggested the implementation of agroforestry systems as an adaption option to enhance small-scale farmers' resilience against climate change in Cameroon. Thus, agroforestry could be an essential agricultural policy framework and a blueprint for member states of the Congo Basin because of its benefits in food security and environmental protection.

Additionally, the long-term equilibrium ARDL/PMG estimations insinuates that LGLO exerts positive and statistically significant impacts on LCO_2. As illustrated in Table 8, this outcome indicates that LCO_2 increases by 0.749885 following a unit increase in LGLO across the Congo Basin enclave. The positive effects of globalization on the environment has been reported by Adebayo and Kirikkaleli (2021) in the case of Japan, Le and Ozturk (2020) in the case of seven emerging economies, and Baajike et al. (2022) in the ECOWAS. Early studies suggest that excessive forest cutting and degradation that happened in the Congo Basin over the years are because of globalization (Nwonwu 2005). For the past few decades, Congo Basin countries have witnessed unbalance trade outcomes with its external partner especially in terms of wood production. On top of that, the continuous deforestation and the subsequent transformation of woodland to arable space and other land uses could be attributed to distant drivers such as globalization. To curb degradation, governments and policymakers across the Basin could implement operational policies and investment actions on aspects of globalization that are detrimental to the environment. This will go a long way to supplement the global green forest policy. However, such policies and investments would yield no positive outcome unless corruption is combatted, institutions are strengthened and sustainable forest management standards are developed while incorporating local stakeholders in the management process. Based on this understanding, policymakers and governments across the region could allocate part of their foreign funds to boost environmentally sound projects such promoting agroforestry and the adoption renewable energy technologies particularly biomass. The question remains if governments and policymakers in this enclave are ready to cooperate and commit to foster SDGs that align the socio-economic path with low carbon development policies.

Lastly, the long-term connection between LURBN and LCO_2 registered a negative and significant coefficient. This indicates that a unit increase in LURBN reduces LCO_2 by −1.713214 (see Table 8). This finding contradicts hypothesis 5 (H_5) which states that urbanization is detrimental to environmental quality at the Congo Basin. Balsalobre-Lorente et al. (2022) support these results for the BRICS, Nathaniel and Adeleye (2021) for selected African countries but contrary to the findings of Sun et al. (2022) for MENA countries. This outcome is instinctive as it admits that there is inclination towards renewable energy usage as population grows. Additionally, the finding indicates that the urban population of these economies is well educated on the need to preserve the environment, and hence a boost to environmental quality. This is a significant contribution to literature as prior studies contradicts this finding. Based on the SDG report for Africa, among the Congo Basin countries, the DRC has one of the fastest growing urban population in the region and has the third largest urban population in SSA and it is expected to grow at the rate 4.1% per annum. Such staggering growth rates require that governments should make cities inclusive and conducive by meeting high request for infrastructure, social services, health, education, and other basic services as well as addressing the absence of focused economic activities in order to make other cities more productive. The same report argues that cities in this region are growing at different rates across different countries with more infrastructures and services concentrated in the capital and economic capital cities. In order to curb unplanned urbanization, governments and policy makers in this region should focus on building robust institutions to combat corruption and put in place infrastructures that would help each urban agglomeration to respond to its own needs to better reap the benefits that comes with economic agglomeration. This will go a long way to help limit urban pollution and make cities livable.

Robustness check with fully modified ordinary least square (FMOLS)

The outcomes of the FMOLS (Table 9) point out that the independent variables (i.e., LGDP, LBIO, LALUC, LGLO, and LURBN) jointly explain 96.97% of variations in the dependent variable (LCO_2).

According to Pedroni (2001), undesirable restrains in estimations could results to biased regressions created by endogeneity and serial correlation. Hence, by basing on non-parametric procedures, FMOLS estimator can effectively get rid of serial correlation and endogeneity disturbances in heterogeneous panels. The outcomes of the FMOLS robustly validate the power of the ARDL/PMG which is the main estimator in this study given that the coefficients for both estimates concurs in terms of signs (negative or positive signs) and statistical significance.

Table 9 Panel FMOLS estimates

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LGDP	1.177501*	0.031912	36.89870	0.0000
LBIO	−0.447117*	0.062826	−7.116737	0.0000
LALUC	−0.993878*	0.046497	−21.37524	0.0000
LGLO	1.232823*	0.071785	17.17378	0.0000
LURBN	−0.250260*	0.028230	−8.864895	0.0000
R-squared	0.969760	Mean dependent var		−0.310194
Adjusted *R*-squared	0.967150	S.D. dependent var		0.736700
S.E. of regression	0.133525	Sum squared resid		2.478205
Long-run variance	0.012933			

*$p < 0.01$

Panel causality estimates

The causal effects of LALUC, LGLO, LGDP, LBIO, and LURBN on LCO_2 are also assess in the Congo Basin.

As illustrated in Table 10, the findings depicts a causal links running from LGDP to LCO_2, LALUC to LCO_2, and from LBIO to LCO_2 without rebound effects. This shows that LGDP, LALUC, and LUBIO can forecast carbon dioxide emissions in the panel. However, there is lack of causal connection between LURBN to LCO_2 and LGLO to LCO_2. These findings call for policy action in the Congo Basin. Finally, Fig. 4 summarizes the outcomes of ARDL/PMG, FMOLS, and D-H panel causality estimates.

Conclusions

As the Earth continue to warm up, environmental issues remain a subject of utmost attention to researchers. While numerous scholars have examined the determinants of environmental quality, a wholesale of studies have dwelled on role of globalization within specific countries in developing, emerging and developed economies. However, little or no attention has been given to the role of globalization in tropical countries. As addition to literature regarding factors affecting environmental quality, the present research investigated the role of agricultural land use change, globalization, biomass energy consumption and urbanization in the growth-environment link for the Congo Basin-the world's largest carbon sink.

Varied primary tests and panel related analytical checks were utilized in this study to uncover features of the selected dataset, which spans from 1980 to 2018. Few advanced panel estimation techniques were employed as robustness checks to complement the ARDL/PMG estimator. The research utilized the CIPS and CADF unit root checks, which revealed that at level, few variables had unit root while the overall series were stationary at first differenced. The bootstrapped co-integration outcome indicated that LCO_2, LALUC, LGLO, LGDP, LBIO, and URBN have a long-run association. The ARDL/PMG estimator revealed that LGDP and LGLO increases LCO_2 in the Congo Basin, while LALUC, LBIO, and URBN reduce LCO_2. The key merits of the ARDL/PMG revolve around the idea that it allows for heterogeneity in panels in the short but restricts it in the long-term in favor of homogeneity. Thus, this is crucial for vigorous and in-depth assessment of the empirical link amongst the variables.

While CO_2 emissions remain a great proxy for environmental quality, emission levels across the Congo Basin are relatively lower compared to that of other tropical countries such as Brazil and Indonesia. Therefore, CO_2 emissions may not be a suitable proxy for evaluating environmental degradation in the Congo Basin. Further research may consider using a more superior environmental quality proxy such as ecological footprint since it incorporates CO_2 emissions in its dataset. Future studies may also consider investigating others determinants of environmental quality in the Congo Basin besides those captured in this study. Furthermore, future studies could also focus on the qualitative determinants of environmental quality in the

Table 10 Dumitrescu Hurlin (D-H) panel causality estimates

Null Hypothesis (H_0):	W-Stat.	Zbar-Stat.	Prob.	Decision
LGDP→LCO2	6.52724	2.29352	0.0218**	Reject H_0
LBIO →LCO2	8.57197	3.71247	0.0002*	Reject H_0
LALUC→LCO2	7.61504	3.04840	0.0023*	Reject H_0
LGLO→ LCO2	2.58317	−0.44347	0.6574	Do not reject H_0
LURBN→LCO2	4.84537	1.12639	0.2600	Do not reject H_0

* and ** represent $p < 0.01$ and $p < 0.05$, respectively

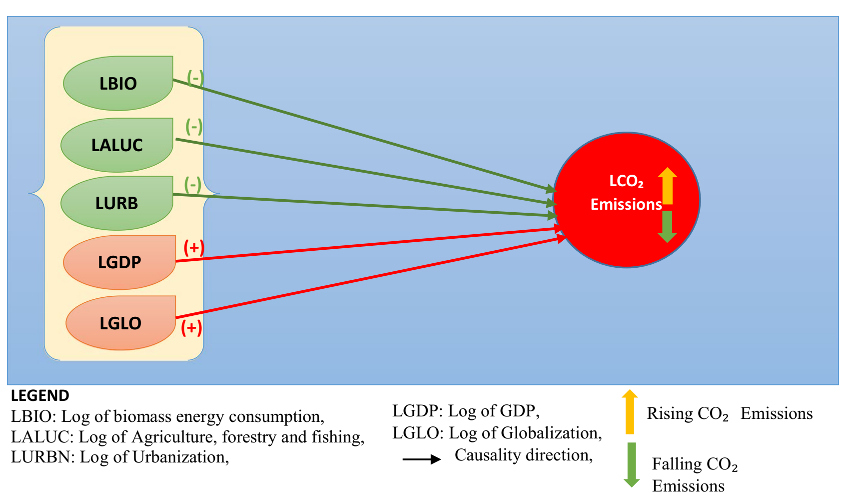

Fig. 4 Graphical outcome of ARDL/PMG, FMOLS, and D-H causality

Congo Basin or other basins across the globe using socio-economic data while comparing the findings with those obtained in this research. Such studies could be project-based incorporating multiple actors. Such a project would go a long way to identify, assess, and address the uneven impacts on different social groups and regions.

Policy implications

The outcomes of this study could proof insightful for the current global efforts to limit forest loss in tropical countries especially through Nationally Determined Contributions (NDC), Forest Law Enforcement, Governance and Trade (FLEGT) and Reducing Emissions from Deforestation and forest Degradation (REDD+). For these giant projects to yield reliable outcomes, the rights and interests of the local population must be protected because the forest has served as their main source of livelihood for centuries.

This research further indicates that countries in the Congo Basin panel are entangled with two wavering interests. (i) The national goals of implementing strategic plans and achieving growth and development as is the case with the Republic of Congo and Democratic Republic of Congo by 2024, Gabon by 2025, and Cameroon by the year 2035. (ii) The collective goal of lowering deforestation and forest degradation and maintaining their lead in carbon sequestration and benefiting from the "loss and damage" fund for susceptible developing nations as outlined in the recent COP27 in Egypt. The loss and damage funds would serve as a remedy to reduce emissions and respond to the injury caused by the damaging impacts of climate change. Being cognizant of these interests will enable governments and policymakers of these countries to initiate environmentally friendly projects such as using degraded surfaces for agro-industrial projects.

In addition, initiatives to reduce forest cutting are far-fetched, and governments of these countries are yet to differentiate underlying causes from distant drivers. Despite national governments' strategic plans of becoming emerging nations through infrastructure enhancement, exportation of minerals and agro-industrial goods, problems such as corruption, inter-ministerial dishonesty, disjointed laws, and imprecise legal systems related to forest preservation still prevail. In this regard, policy and institutional drivers count amongst the significant drivers of forest loss (Wehkamp et al. 2015). Furthermore, through globalization, foreign trade between countries of the Congo Basin and the rest of the world have received unbalance outcomes for its manufacturing sectors, as wood from the Basin have been exported in primary form with minimal secondary and tertiary transformations. Consequently, the constant cutting down of forest and the subsequent conversion of previous forestlands into cultivable space and other land uses could be because of distant factors such as globalization. Given these scenarios, Congo Basin governments and policymakers should channel foreign funds towards environmental benign projects such as investing in renewable energy, particularly biomass that abound in huge quantities in the entire region. For this to be effective, cooperation and political commitments are required for Congo Basin governments to incorporate and foster sustainable development goals that could align their socio-economic plans with low carbon development policies.

In terms of land use, this study found that agricultural expansion characterized by subsistence farming, bush fallowing, and agro-industrial plantations features among the proximate cause of deforestation and forest degradation in the Congo Basin. In so far, as the conversion of forest to farmland and other uses remains beneficial for the local population, it also degrades forest cover and soil biota which potential increase emissions in the enclave. Hence, investments in the agricultural sector should prioritize environmentally benign practices such as agroforestry. Environmental benign practices and economic productivity stress on the need to put in place improved and efficient systems, domesticate enhanced native species, incorporate small-stock creation into the structure, and put in place marketable, protective, and engaging policy frameworks within agroforestry system that caters for land tenue and the conversion of local products. Besides the socio-economic and cultural gains of agroforestry to agricultural practitioners (especially small-scale farmers and grazers), it also enhances environmental quality as it conserves biodiversity, sequesters CO_2, increases soil productivity, and reduces excessive reliance on natural resources (Awazi et al. 2019). Others studies suggest that allocating land use for agroforestry based on tree crop production like cacao is more environmentally friendly than food crop production because the former depends on bush fallowing system of farming, which owing to human pressure on land and decrease fallow cycle is becoming obsolete and unsustainable (Duguma et al. 2001). The same study pointed out that agroforestry system controls for soil nutrients loss, as fast-growing trees species (like Eucalyptus grandis, Calliandra calothyrsus, and Sesbania sesban) take up subsoil nitrates more efficiently compared to the speed at which normal pasture fallow extracts subsoil water. This aligns with Awazi et al. (2020) who strongly recommended agroforestry in Cameroon and across sub Saharan Africa as a remedy to combat the nefarious effects of global warming and climate change. In addition, agricultural expansion seems not to end anytime soon; thus, land use policies should be geared towards prioritizing and revamping degraded and low carbon areas. However, the question remains whether governments and policymakers of this Basin will give sustainable forest development policies a chance to prevail at the national and regional levels.

Awareness and perception of policymakers towards low carbon development plans have recently been noticed in Congo Basin's policy strategies as evident in the "regional green economy strategy." This strategy is aimed at achieving economic growth with minimal impacts on the environment (Hapres 2022). Nevertheless, the question remains whether these strategies will adequately move the powers concerned in to action. In the best-case scenario, these strategies must be accompanied by concrete land use plans that can assist in striking a balance amongst activities carried out on different land compartments. Such efforts can yield positive outcomes if the authorities (ministries of forestry and wildlife, agriculture, mines, and resource management) work in collaboration with local authorities. Amongst Congo Basin countries, Gabon has already developed and integrated CO_2 reduction plan in its country's land use plan (Tegegne et al. 2016). This could serve a blueprint for other countries in the Basin to follow.

A key element regarding CO_2 reduction strategies remains the cost that may accompany the implementation of such plans. Within this framework, global talks on REDD+ finance may be a huge influencer when deciding on policy directions to follow. While REDD+ sponsors notably Norway have successfully engaged in bilateral agreements with numerous tropical countries like Indonesia, Tanzania, Brazil, and Peru, such monetary engagements are yet to be seen in the Congo Basin. REDD+ financial intervention could be a huge booster for the Congo Basin countries, given that the governing regimes and policymakers in these countries could incredulously shy away from deals regarding the cutting down of trees. Thus, emission reduction initiatives through the REDD+ mechanism must be financially appealing to lessen the activities related to agro-industrial expansion that aggravates the cutting of forests.

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Data availability Data utilized for this study is accessible from the World Bank, Our World in Data, International Resource Panel, and Swiss Economic Institute as indicated in Table 2.

Declarations

Ethics approval The authors confirmed that this manuscript has not been published somewhere else and is not under consideration by another journal. Thus, informed consent and ethical approval do not apply for this research.

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References

Abbasi KR, Shahbaz M, Jiao Z, Tufail M (2021) How energy consumption, industrial growth, urbanization, and CO_2 emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach. Energy 221:119793. https://doi.org/10.1016/j.energy.2021.119793

Abernethy K, Maisels F, White LJ (2016) Environmental issues in central Africa. Annu Rev Environ Resour 41(1):1–33. https://doi.org/10.1146/annurev-environ-110615-085415

Acheampong AO, Adams S, Boateng E (2019) Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? Sci Total Environ 677:436–446. https://doi.org/10.1016/j.scitotenv.2019.04.353

Addai K, Serener B, Kirikkaleli D (2022) Environmental sustainability and regulatory quality in emerging economies: empirical evidence from Eastern European Region. J Knowl Econ 1-37. https://doi.org/10.1007/s13132-022-01000-2

Adebayo TS, Kirikkaleli D (2021) Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools. Environ Dev Sustain 23(11):16057–16082. https://doi.org/10.1007/s10668-021-01322-2

Adebayo TS, Awosusi AA, Rjoub H, Agyekum EB, Kirikkaleli D (2022a) The influence of renewable energy usage on consumption-based carbon emissions in MINT economies. Heliyon 8(2):e08941. https://doi.org/10.1016/j.heliyon.2022.e08941

Adebayo TS, Onifade ST, Alola AA, Muoneke OB (2022b) Does it take international integration of natural resources to ascend the ladder of environmental quality in the newly industrialized countries? Res Policy 76:102616. https://doi.org/10.1016/j.resourpol.2022.102616

Adedoyin FF, Alola AA, Bekun FV (2020) An assessment of environmental sustainability corridor: the role of economic expansion and research and development in EU countries. Sci Total Environ 713:136726. https://doi.org/10.1016/j.scitotenv.2020.136726

African Natural Resources Centre (ANRC) (2021) Economic performance of the Congo Basin's forestry sector. African Development Bank Abidjan, Côte d'Ivoire https://www.afdb.org/en/documents/policy-brief-economic-performance-congo-basins-forestry-sector Accessed 20/02/2023

Ahmad Z, Baig IA, Husain S, Khan ZA, Rana M, Azam K, Salam MA (2023) How technological innovation and electricity consumption affect environmental quality? A road map towards achieving environmental sustainability. Environ Sci Pollut Res 1-18. https://doi.org/10.1007/s11356-023-28055-1

Ahmed Z, Asghar MM, Malik MN, Nawaz K (2020) Moving towards a sustainable environment: the dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. Res Policy 67:101677. https://doi.org/10.1016/j.resourpol.2020.101677

Alexander P, Rounsevell MD, Dislich C, Dodson JR, Engström K, Moran D (2015) Drivers for global agricultural land use change: the nexus of diet, population, yield and bioenergy. Glob Environ Chang 35:138–147. https://doi.org/10.1016/j.gloenvcha.2015.08.011

Anderson EP, Osborne T, Maldonado-Ocampo JA, Mills-Novoa M, Castello L, Montoya M et al (2019) Energy development reveals blind spots for ecosystem conservation in the Amazon Basin. Front Ecol Environ 17(9):521–529. https://doi.org/10.1002/fee.2114

Aquilas NA, Mukong AK, Kimengsi JN, Ngangnchi FH (2022) Economic activities and deforestation in the Congo Basin: an environmental Kuznets curve framework analysis. Environ Challenges 100553. https://doi.org/10.1016/j.envc.2022.100553

Awan AM, Azam M, Saeed IU, Bakhtyar B (2020) Does globalization and financial sector development affect environmental quality? A panel data investigation for the Middle East and North African countries. Environ Sci Pollut Res 27(36):45405–45418. https://doi.org/10.1007/s11356-020-10445-4

Awazi NP, Tchamba MN, Avana TML (2019) Climate change resiliency choices of small-scale farmers in Cameroon: determinants and policy implications. J Environ Manag 250:109560. https://doi.org/10.1016/j.jenvman.2019.109560

Awazi NP, Tchamba MN, Temgoua LF, Avana MLT (2020) Appraisal of smallholder farmers' vulnerability to climatic variations and changes in the Western Highlands of Cameroon. Sci African 10:e00637. https://doi.org/10.1007/s10457-020-00537-y

Awazi NP, Tchamba MN, Temgoua LF (2021) Climate-smart practices of smallholder farmers in Cameroon confronted with climate variability and change: the example of agroforestry. Agric Res 10:83–96. https://doi.org/10.1007/s40003-020-00477-0

Awazi NP, Tchamba MN, Temgoua LF et al (2022) Agroforestry as an adaptation option to climate change in Cameroon: assessing farmers' preferences. Agric Res **11**:309–320. https://doi.org/10.1007/s40003-021-00562-y

Awosusi AA, Adebayo TS, Altuntaş M, Agyekum EB, Zawbaa HM, Kamel S (2022) The dynamic impact of biomass and natural resources on ecological footprint in BRICS economies: a quantile regression evidence. Energy Rep 8:1979–1994. https://doi.org/10.1016/j.egyr.2022.01.022

Aydoğan B, Vardar G (2020a) Evaluating the role of renewable energy, economic growth and agriculture on CO_2 emission in E7 countries. Int J Sustain Energ 39(4):335–348. https://doi.org/10.1080/14786451.2019.1686380

Aydoğan B, Vardar G (2020b) Evaluating the role of renewable energy, economic growth and agriculture on CO_2 emission in E7 countries. Int J Sustain Energy 39(4):335–348. https://doi.org/10.1080/14786451.2019.1686380

Baajike FB, Ntsiful E, Afriyie AB, Oteng-Abayie EF (2022) The effects of economic growth, trade liberalization, and financial development on environmental sustainability in West Africa. The role of institutions. Res Globaliz 5:100104. https://doi.org/10.1016/j.resglo.2022.100104

Baig IA, Chandio AA, Ozturk I, Kumar P, Khan ZA, Salam MA (2022) Assessing the long-and short-run asymmetrical effects of climate change on rice production: empirical evidence from India. Environ Sci Pollut Res 1-22. https://doi.org/10.1007/s11356-021-18014-z

Baig IA, Irfan M, Aarif M, Husain S, Sulaiman M (2023a) How agricultural technologies and climatic factors affect India's crop production? A roadmap towards sustainable agriculture. Sustain Dev. https://doi.org/10.1002/sd.2558

Baig IA, Irfan M, Salam MA, Işik C (2023) Addressing the effect of meteorological factors and agricultural subsidy on agricultural productivity in India: a roadmap toward environmental sustainability. Environ Sci Pollut Res 30(6):15881–15898. https://doi.org/10.1007/s11356-022-23210-6

Baloch MA, Ozturk I, Bekun FV, Khan D (2021) Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: does globalization matter? Bus Strateg Environ 30(1):176–184. https://doi.org/10.1002/bse.2615

Balsalobre-Lorente D, Driha OM, Halkos G, Mishra S (2022) Influence of growth and urbanization on CO_2 emissions: the moderating effect of foreign direct investment on energy use in BRICS. Sustain Dev 30(1):227–240. https://doi.org/10.1002/sd.2240

Baltagi BH, Kao C, Peng B (2016) Testing cross-sectional correlation in large panel data models with serial correlation. Econometrics 4(4):44. https://doi.org/10.3390/econometrics4040044

Bellarby, J., Foereid, B., & Hastings, A. (2008). Cool farming: climate impacts of agriculture and mitigation potential. https://eprints.lancs.ac.uk/id/eprint/68831/1/1111.pdf. Accessed 15/02/2023

Ben Jebli M, Ben Youssef S (2017) Renewable energy, arable land, agriculture, CO_2 emissions, and economic growth in Morocco. https://mpra.ub.uni-muenchen.de/id/eprint/76798

Bilgili F, Ulucak R, Koçak E, İlkay SÇ (2020) Does globalization matter for environmental sustainability? Empirical investigation for Turkey by Markov regime switching models. Environ Sci Pollut Res 27:1087–1100. https://doi.org/10.1007/s11356-019-06996-w

Blomquist J, Westerlund J (2013) Testing slope homogeneity in large panels with serial correlation. Econ Lett 121(3):374–378. https://doi.org/10.1016/j.econlet.2013.09.012

Buyantuyev A, Wu J (2009) Urbanization alters spatiotemporal patterns of ecosystem primary production: a case study of the Phoenix metropolitan region, USA. J Arid Environ 73(4-5):512–520. https://doi.org/10.1016/j.jaridenv.2008.12.015

Carter S (2018) Deforestation and agriculture in the tropics: carbon emissions and options for mitigation (Doctoral dissertation,. Wageningen University and Research), p 164. https://doi.org/10.18174/428320

Chishti MZ, Ullah S, Ozturk I, Usman A (2020) Examining the asymmetric effects of globalization and tourism on pollution emissions in South Asia. Environ Sci Pollut Res 27(22):27721–27737. https://doi.org/10.1007/s11356-020-09057-9

Chudik A, Pesaran MH, Tosetti E (2011) Weak and strong cross-section dependence and estimation of large panels https://doi.org/10.1111/j.1368-423X.2010.00330.x

Destek MA, Sinha A (2020) Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: evidence from organisation for economic Co-operation and development countries. J Clean Prod 242:118537. https://doi.org/10.1016/j.jclepro.2019.118537

Dogan E, Inglesi-Lotz R (2017) Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO_2) emissions: empirical evidence from the panel of biomass-consuming countries. Energy 138:721–727. https://doi.org/10.1016/j.energy.2017.07.136

Dogan E, Turkekul B (2016) CO_2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res 23(2):1203–1213. https://doi.org/10.1007/s11356-015-5323-8

Duguma B, Gockowski J, Bakala J (2001) Smallholder cacao (Theobroma cacao Linn.) cultivation in agroforestry systems of West and Central Africa: challenges and opportunities. Agrofor Syst 51(3):177–188. https://doi.org/10.1023/A:1010747224249

Dumrul Y, Bilgili F, Dumrul C, Kılıçarslan Z, Rahman MN (2023) The impacts of renewable energy production, economic growth, and economic globalization on CO_2 emissions: evidence from Fourier ADL co-integration and Fourier-Granger causality test for Turkey. Environ Sci Pollut Res 30(41):94138–94153. https://doi.org/10.1007/s11356-023-28800-6

FAO (2017) FAOSTAT Statistics Database. Available at: http://www.fao.org/faostat/

Farooq S, Ozturk I, Majeed MT, Akram R (2022) Globalization and CO_2 emissions in the presence of EKC: a global panel data analysis. Gondwana Res 106:367–378. https://doi.org/10.1016/j.gr.2022.02.002

Fopa VK, Bayir N, Özdal D (2023) Assessing the status and spatial-temporal dynamics of the Bamenda Mountains (BM), North West region of Cameroon. Environ Monit Assess 195(9):1–27. https://doi.org/10.1007/s10661-023-11630-x

Frankel, J. A. (2003). The environment and globalization. http://www.nber.org/papers/w10090
Friel S, Dangour AD, Garnett T, Lock K, Chalabi Z, Roberts I et al (2009) Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture. Lancet 374(9706):2016–2025. https://doi.org/10.1016/S0140-6736(09)61753-0
Galpern DM (2021) A view from Glasgow. Sustainability and Climate Change 14(6):360–365. https://doi.org/10.1089/scc.2021.0079
Gancia G, Ponzetto GA, Ventura J (2022) Globalization and political structure. J Eur Econ Assoc 20(3):1276–1310. https://doi.org/10.1093/jeea/jvac019
Gao J, Zhang L (2021) Does biomass energy consumption mitigate CO_2 emissions? The role of economic growth and urbanization: evidence from developing Asia. J Asia Pac Econ 26(1):96–115. https://doi.org/10.1080/13547860.2020.1717902
Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement. https://doi.org/10.3386/w3914
Güney T, Kantar K (2020) Biomass energy consumption and sustainable development. Int J Sustain Dev World Ecol 27(8):762–767. https://doi.org/10.1080/13504509.2020.1753124
Hapres L (2022) Africa blue economy strategies integrated in planning to achieve sustainable development at national and regional economic communities (RECs). https://doi.org/10.20900/jsr20220011
Hoyle, D., & Levang, P. (2012). Oil palm development in Cameroon. An ad hoc working paper prepared by WWF, IRD and CIFOR. http://awsassets.panda.org/downloads/palmoildevelopmentcameroon_english.pdf Accessed 15/02/2023.
International Resource Panel (IRP). (2023). Global material flows database, supporting evidence-based decision-making by policy and business communities. https://www.resourcepanel.org/global-material-flows-database (Accessed 4/01/2023).
IPCC (2021) Climate Change and Land, An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, Summary for Policymakers. SPM_Updated-Jan20.pdf (ipcc.ch)
Işık C (2013) The importance of creating a competitive advantage and investing in information technology for modern economies: An ARDL test approach from Turkey. J Knowl Econ 4:387–405. https://doi.org/10.1007/s13132-011-0075-2
Işık C, Ahmad M, Ongan S, Ozdemir D, Irfan M, Alvarado R (2021c) Convergence analysis of the ecological footprint: theory and empirical evidence from the USMCA countries. Environ Sci Pollut Res 28:32648–32659. https://doi.org/10.1007/s11356-021-12993-9
Işık C, Ongan S, Bulut U, Karakaya S, Irfan M, Alvarado R et al (2021b) Reinvestigating the Environmental Kuznets Curve (EKC) hypothesis by a composite model constructed on the Armey curve hypothesis with government spending for the US States. Environ Sci Pollut Res 1-12. https://doi.org/10.1007/s11356-021-16720-2
Isik C, Ongan S, Ozdemir D, Ahmad M, Irfan M, Alvarado R, Ongan A (2021a) The increases and decreases of the environment Kuznets curve (EKC) for 8 OECD countries. Environ Sci Pollut Res 28:28535–28543. https://doi.org/10.1007/s11356-021-12637-y
Jahanger A (2022) Impact of globalization on CO2 emissions based on EKC hypothesis in developing world: the moderating role of human capital. Environ Sci Pollut Res 29(14):20731–20751. https://doi.org/10.1007/s11356-021-17062-9
Jahanger A, Usman M, Balsalobre-Lorente D (2022) Autocracy, democracy, globalization, and environmental pollution in developing world: fresh evidence from STIRPAT model. J Public Aff 22(4):e2753. https://doi.org/10.1002/pa.2753
Jahanger A, Yang B, Huang WC, Murshed M, Usman M, Radulescu M (2022a) Dynamic linkages between globalization, human capital, and carbon dioxide emissions: empirical evidence from developing economies. Environ Dev Sustain 1-29. https://doi.org/10.1007/s10668-022-02437-w
Jebli MB, Youssef SB (2015) The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia. Renew Sust Energ Rev 47:173–185. https://doi.org/10.1016/j.rser.2015.02.049
Jebli MB, Youssef SB (2017) The role of renewable energy and agriculture in reducing CO2 emissions: evidence for North African countries. Ecol Indic 74:295–301. https://doi.org/10.1016/j.ecolind.2016.11.032
Jones BF, Liu X (2022) A framework for economic growth with capital-embodied technical change (No. w30459). National Bureau of Economic Research. https://doi.org/10.3386/w30459
Kalaycı C, Hayaloğlu P (2019) The impact of economic globalization on CO_2 emissions. https://doi.org/10.32479/ijeep.7233
Kirikkaleli D (2020) New insights into an old issue: exploring the nexus between economic growth and CO_2 emissions in China. Environ Sci Pollut Res 27(32):40777–40786. https://doi.org/10.1007/s11356-020-10090-x
Kirikkaleli D, Adebayo TS (2021) Do public-private partnerships in energy and renewable energy consumption matter for consumption-based carbon dioxide emissions in India? Environ Sci Pollut Res 28(23):30139–30152. https://doi.org/10.1007/s11356-021-12692-5
Kirikkaleli D, Adebayo TS, Khan Z, Ali S (2021) Does globalization matter for ecological footprint in Turkey? Evidence from dual adjustment approach. Environ Sci Pollut Res 28(11):14009–14017. https://doi.org/10.1007/s11356-020-11654-7
Kirikkaleli D, Güngör H, Adebayo TS (2022) Consumption-based carbon emissions, renewable energy consumption, financial development and economic growth in Chile. Bus Strateg Environ 31(3):1123–1137. https://doi.org/10.1002/bse.2945
Kishor N, Lescuyer G (2012) Controlling illegal logging in domestic and international markets by harnessing multi-level governance opportunities. Int J Commons 6(2) https://doi.org/10.18352/ijc.327
KOF Swiss Economic Institute, 2022. KOF globalisation index. https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html. (Accessed on 5 January, 2023).
Kongkuah M, Yao H, Yilanci V (2022) The relationship between energy consumption, economic growth, and CO_2 emissions in China: the role of urbanisation and international trade. Environ Dev Sustain 24(4):4684–4708. https://doi.org/10.1007/s10668-021-01628-1
Krey, V., Masera, O., Blanford, G., Bruckner, T., Cooke, R., Fisher-Vanden, K., ... & Zwickel, T. (2014). Annex 2-metrics and methodology. https://pure.iiasa.ac.at/11109
Le HP, Ozturk I (2020) The impacts of globalization, financial development, government expenditures, and institutional quality on CO_2 emissions in the presence of environmental Kuznets curve. Environ Sci Pollut Res 27(18):22680–22697. https://doi.org/10.1007/s11356-020-08812-2
Leal PH, Marques AC (2020) Rediscovering the EKC hypothesis for the 20 highest CO_2 emitters among OECD countries by level of globalization. Int Econ 164:36–47. https://doi.org/10.1016/j.inteco.2020.07.001
Lee CC, Lee CC, Xiao S (2021) Policy-related risk and corporate financing behavior: evidence from China's listed companies. Econ Model 94:539–547. https://doi.org/10.1016/j.econmod.2020.01.022
Liang L, Wang Z, Li J (2019) The effect of urbanization on environmental pollution in rapidly developing urban agglomerations. J

Clean Prod 237:117649. https://doi.org/10.1016/j.jclepro.2019.117649

Liu H, Gong P, Wang J, Clinton N, Bai Y, Liang S (2020) Annual dynamics of global land cover and its long-term changes from 1982 to 2015. Earth System Science Data 12(2):1217–1243. https://doi.org/10.5194/essd-12-1217-2020

Liu Z, Saydaliev HB, Lan J, Ali S, Anser MK (2022) Assessing the effectiveness of biomass energy in mitigating CO_2 emissions: evidence from Top-10 biomass energy consumer countries. Renew Energy 191:842–851. https://doi.org/10.1016/j.renene.2022.03.053

Lu XB (ed) (2016) Carbon dioxide and organometallics. Springer International Publishing, Cham

Majeed MT, Mazhar M (2019) Financial development and ecological footprint: a global panel data analysis. Pakistan J Commerce Soc Sci (PJCSS) 13(2):487–514 http://hdl.handle.net/10419/201002

Malik MA (2021) Economic growth, energy consumption, and environmental quality nexus in Turkey: evidence from simultaneous equation models. Environ Sci Pollut Res 28(31):41988–41999. https://doi.org/10.1007/s11356-021-13468-7

Matson PA, McDOWELL WH, Townsend AR, Vitousek PM (1999) The globalization of N deposition: ecosystem consequences in tropical environments. Biogeochemistry 46:67–83. https://doi.org/10.1023/A:1006152112852

McCoskey S, Kao C (1998) A residual-based test of the null of cointegration in panel data. Econ Rev 17(1):57–84. https://doi.org/10.1080/07474939808800403

Megevand C, Mosnier A (2013) Deforestation trends in the Congo Basin: reconciling economic growth and forest protection. World Bank Publications

Mehmood U (2022) The role of economic globalization in reducing CO_2 emissions: implications for sustainable development in South Asian nations. Environ Dev Sustain 1-13. https://doi.org/10.1007/s10668-022-02823-4

Nathaniel SP, Adeleye N (2021) Environmental preservation amidst carbon emissions, energy consumption, and urbanization in selected African countries: implication for sustainability. J Clean Prod 285:125409. https://doi.org/10.1016/j.jclepro.2020.125409

Nkongho RN, Feintrenie L, Levang P (2014) Strengths and weaknesses of the smallholder oil palm sector in Cameroon. https://doi.org/10.1051/ocl/2013043

Nkonya, E., Karsenty, A., Msangi, S., Souza Jr, C., Shah, M., Von Braun, J., ... & Park, S. (2012). Sustainable land use for the 21st century (SD21). Microsoft Word - sustainable land use final.doc (http://cirad.fr)

Nwonwu FOC (2005) The Congo basin at the crossroads: managing or mining the forests? African Forests Between Nat Livelihood Resour:31–66 https://www.cabdirect.org/cabdirect/abstract/20066710062

Osland, J. S., Dhanda, K., & Yuthas, K. (2002). Globalization and environmental sustainability: An analysis of the impact of globalization using the Natural Step framework. Research in corporate sustainability: The evolving theory and practice of organizations in the natural environment, 31-60. https://pdxscholar.library.pdx.edu/cgi/viewcontent.cgi?article=1008&context=busadmin_fac. Accessed 20/02/2023.

Our World in Data. 2023. co2-emissions. https://ourworldindata.org/co2-emissions. (Accessed on 5 January, 2023).

Panayotou T (1995) Environmental degradation at different stages of economic development. Beyond Rio 13–36. https://doi.org/10.1007/978-1-349-24245-0_2

Pedroni P (2001) Fully modified OLS for heterogeneous cointegrated panels. In: Nonstationary panels, panel cointegration, and dynamic panels. Emerald Group Publishing Limited, pp 93–130. https://doi.org/10.1016/S0731-9053(00)15004-2

Pedroni P (2004) Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Economet Theor 20(3):597–625. https://doi.org/10.1017/S0266466604203073

Pesaran MH, Shin Y, Smith RP (1999) Pooled mean group estimation of dynamic heterogeneous panels. J Am Stat Assoc 94(446):621–634. https://doi.org/10.1080/01621459.1999.10474156

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Econ 22(2):265–312. https://doi.org/10.1002/jae.951

Pesaran MH (2015) Testing weak cross-sectional dependence in large panels. Econ Rev 34(6-10):1089–1117. https://doi.org/10.1080/07474938.2014.956623

Pesaran MH, Yamagata T (2008) Testing slope homogeneity in large panels. J Econ 142(1):50–93. https://doi.org/10.1016/j.jeconom.2007.05.010

Phillips PC, Sul D (2003) Dynamic panel estimation and homogeneity testing under cross section dependence. Econ J 6(1):217–259. https://doi.org/10.1111/1368-423X.00108

Rafiq S, Salim R, Apergis N (2016) Agriculture, trade openness and emissions: an empirical analysis and policy options. Aust J Agric Resour Econ 60(3):348–365. https://doi.org/10.1111/1467-8489.12131

Raihan A (2023) The dynamic nexus between economic growth, renewable energy use, urbanization, industrialization, tourism, agricultural productivity, forest area, and carbon dioxide emissions in the Philippines. Energy Nexus 9:100180. https://doi.org/10.1016/j.nexus.2023.100180

Raihan A, Tuspekova A (2022) Toward a sustainable environment: nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. Resour , Conserv Recycl Adv 15:200096. https://doi.org/10.1016/j.rcradv.2022.200096

Raihan A, Ibrahim S, Muhtasim DA (2023a) Dynamic impacts of economic growth, energy use, tourism, and agricultural productivity on carbon dioxide emissions in Egypt. World Dev Sustain 2:100059. https://doi.org/10.1016/j.wds.2023.100059

Raihan A, Muhtasim DA, Farhana S, Hasan MAU, Pavel MI, Faruk O et al (2023c) An econometric analysis of greenhouse gas emissions from different agricultural factors in Bangladesh. Energy Nexus 9:100179. https://doi.org/10.1016/j.nexus.2023.100179

Raihan A, Muhtasim DA, Farhana S, Rahman M, Hasan MAU, Paul A, Faruk O (2023b) Dynamic linkages between environmental factors and carbon emissions in Thailand. Environ Proc 10(1):5. https://doi.org/10.1007/s40710-023-00618-x

Ramzan M, Ullah S, Raza SA, Nadeem M (2023) A step towards achieving SDG 2030 agenda: analyzing the predictive power of information globalization amidst technological innovation-environmental stewardship nexus in the greenest economies. J Environ Manag 335:117541. https://doi.org/10.1016/j.jenvman.2023.117541

Raza SA, Qureshi MA, Ahmed M, Qaiser S, Ali R, Ahmed F (2021) Non-linear relationship between tourism, economic growth, urbanization, and environmental degradation: evidence from smooth transition models. Environ Sci Pollut Res 28(2):1426–1442. https://doi.org/10.1007/s11356-020-10179-3

Redford K (1995) Human influences on biodiversity. VH Heywood RT Watson:711–822 https://wgbis.ces.iisc.ernet.in/biodiversity/sdev/mg/pdfs/mg149.pdf

Rehman A, Alam MM, Alvarado R, Işık C, Ahmad F, Cismas LM, Pupazan MCM (2022) Carbonization and agricultural productivity in Bhutan: investigating the impact of crop production, fertilizer usage, and employment on CO2 emissions. J Clean Prod 375:134178. https://doi.org/10.1016/j.jclepro.2022.134178

Robinson GM, Carson DA (2015) The globalisation of agriculture: Introducing the Handbook. In: Handbook on the globalisation of agriculture. Edward Elgar Publishing, pp 1–28. https://doi.org/10.4337/9780857939838.00006

Rosillo-Calle F (2012) Food versus fuel: toward a new paradigm—the need for a holistic approach. Int Scholarly Res Notices 2012. https://doi.org/10.5402/2012/954180

Rudel TK, Schneider L, Uriarte M, Turner BL, DeFries R, Lawrence D et al (2009) Agricultural intensification and changes in cultivated areas, 1970–2005. Proc Natl Acad Sci 106(49):20675–20680. https://doi.org/10.1073/pnas.0812540106

Sadiq M, Wen F (2022) Environmental footprint impacts of nuclear energy consumption: the role of environmental technology and globalization in ten largest ecological footprint countries. Nucl Eng Technol. https://doi.org/10.1016/j.net.2022.05.016

Salahuddin M, Ali MI, Vink N, Gow J (2019) The effects of urbanization and globalization on CO_2 emissions: evidence from the Sub-Saharan Africa (SSA) countries. Environ Sci Pollut Res 26:2699–2709. https://doi.org/10.1007/s11356-018-3790-4

Sarwar S (2019) Role of urban income, industrial carbon treatment plants and forests to control the carbon emission in China. Environ Sci Pollut Res 26(16):16652–16661. https://doi.org/10.1007/s11356-019-04854-3

Sebri M, Ben-Salha O (2014) On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: fresh evidence from BRICS countries. Renew Sust Energ Rev 39:14–23. https://doi.org/10.1016/j.rser.2014.07.033

Selvanathan S, Jayasinghe MS, Selvanathan EA, Abbas SA, Iftekhar MS (2023) Energy consumption, agriculture, forestation and CO_2 emission nexus: an application to OECD countries. Appl Econ 55(37):4359–4376. https://doi.org/10.1080/00036846.2022.2128296

Shah MI, AbdulKareem HK, Ishola BD, Abbas S (2023) The roles of energy, natural resources, agriculture and regional integration on CO_2 emissions in selected countries of ASEAN: Does political constraint matter? Environ Sci Pollut Res 30(10):26063–26077. https://doi.org/10.1007/s11356-022-23871-3

Shahbaz M, Balsalobre-Lorente D, Sinha A (2019) Foreign direct Investment–CO_2 emissions nexus in Middle East and North African countries: importance of biomass energy consumption. J Clean Prod 217:603–614. https://doi.org/10.1016/j.jclepro.2019.01.282

Shahbaz M, Khan S, Ali A, Bhattacharya M (2017a) The impact of globalization on CO_2 emissions in China. The Singapore Economic Review 62(04):929–957. https://doi.org/10.1142/S0217590817400331

Shahbaz M, Nasreen S, Ahmed K, Hammoudeh S (2017b) Trade openness–carbon emissions nexus: the importance of turning points of trade openness for country panels. Energy Econ 61:221–232. https://doi.org/10.1016/j.eneco.2016.11.008

Solarin SA, Al-Mulali U, Gan GGG, Shahbaz M (2018) The impact of biomass energy consumption on pollution: evidence from 80 developed and developing countries. Environ Sci Pollut Res 25(23):22641–22657. https://doi.org/10.1007/s11356-018-2392-5

Sulaiman C, Abdul-Rahim AS (2020) Can clean biomass energy use lower CO_2 emissions in African economies? Empirical evidence from dynamic long-run panel framework. Environ Sci Pollut Res 27(30):37699–37708. https://doi.org/10.1007/s11356-020-09866-y

Sulaiman C, Abdul-Rahim AS, Ofozor CA (2020) Does wood biomass energy use reduce CO_2 emissions in European Union member countries? Evidence from 27 members. J Clean Prod 253:119996. https://doi.org/10.1016/j.jclepro.2020.119996

Sun Y, Li H, Andlib Z, Genie MG (2022) How do renewable energy and urbanization cause carbon emissions? Evidence from advanced panel estimation techniques. Renew Energy 185:996–1005. https://doi.org/10.1016/j.renene.2021.12.112

Swamy PA (1970) Efficient inference in a random coefficient regression model. Econometrica:311–323. https://doi.org/10.2307/1913012

Tegegne YT, Lindner M, Fobissie K, Kanninen M (2016) Evolution of drivers of deforestation and forest degradation in the Congo Basin forests: exploring possible policy options to address forest loss. Land Use Policy 51:312–324. https://doi.org/10.1016/j.landusepol.2015.11.024

The World Bank Group (2022). Journey into the Congo Basin — the lungs of Africa and beating heart of the world. https://www.worldbank.org/en/news/feature/2022/10/24/journey-into-the-congo-basin-the-lungs-of-africa-and-beating-heart-of-the-world Accessed 15/02/2023.

Tongele TN (2021) Human ways of life and environmental sustainability: Congo Basin case study. J Civil Eng Architecture 15:547–559. https://doi.org/10.17265/1934-7359/2021.11.001

Tritsch I, Le Velly G, Mertens B, Meyfroidt P, Sannier C, Makak JS, Houngbedji K (2020) Do forest-management plans and FSC certification help avoid deforestation in the Congo Basin? Ecol Econ 175:106660. https://doi.org/10.1016/j.ecolecon.2020.106660

Tsimisaraka RSM, Xiang L, Andrianarivo ARNA, Josoa EZ, Khan N, Hanif MS, ... Limongi R (2023) Impact of financial inclusion, globalization, renewable energy, ICT, and economic growth on CO_2 emission in OBOR countries. Sustainability 15(8):6534. https://doi.org/10.3390/su15086534

Twerefou DK, Akpalu W, Mensah ACE (2019) Trade-induced environmental quality: the role of factor endowment and environmental regulation in Africa. Clim Dev 11(9):786–798. https://doi.org/10.1080/17565529.2018.1562868

Usman M, Anwar S, Yaseen MR, Makhdum MSA, Kousar R, Jahanger A (2022) Unveiling the dynamic relationship between agriculture value addition, energy utilization, tourism and environmental degradation in South Asia. J Public Aff 22(4):e2712. https://doi.org/10.1002/pa.2712

Waheed R, Chang D, Sarwar S, Chen W (2018) Forest, agriculture, renewable energy, and CO2 emission. J Clean Prod 172:4231–4238. https://doi.org/10.1016/j.jclepro.2017.10.287

Wang C, Zhang X, Liu Q, Zhang Q, Chen L, Ma L (2020) A review of conversion of lignocellulose biomass to liquid transport fuels by integrated refining strategies. Fuel Process Technol 208:106485. https://doi.org/10.1016/j.fuproc.2020.106485

Wang W, Fan LW, Zhou P (2022) Evolution of global fossil fuel trade dependencies. Energy 238(PC). https://doi.org/10.1016/j.energy.2021.121924

Wang C, Raza SA, Adebayo TS, Yi S, Shah MI (2023) The roles of hydro, nuclear and biomass energy towards carbon neutrality target in China: a policy-based analysis. Energy 262:125303. https://doi.org/10.1016/j.energy.2022.125303

Wasti SKA, Zaidi SW (2020) An empirical investigation between CO_2 emission, energy consumption, trade liberalization and economic growth: A case of Kuwait. J Build Eng 28:101104. https://doi.org/10.1016/j.jobe.2019.101104

Wehkamp J, Aquino A, Fuss S, Reed EW (2015) Analyzing the perception of deforestation drivers by African policy makers in light of possible REDD+ policy responses. Forest Policy Econ 59:7–18. https://doi.org/10.1016/j.forpol.2015.05.005

Wen J, Mughal N, Zhao J, Shabbir MS, Niedbała G, Jain V, Anwar A (2021) Does globalization matter for environmental degradation? Nexus among energy consumption, economic growth, and carbon dioxide emission. Energy Policy 153:112230. https://doi.org/10.1016/j.enpol.2021.112230

Westerlund J (2007) Testing for error correction in panel data. Oxf Bull Econ Stat 69(6):709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

World Bank, 2023. World Development Indicators. https://data.worldbank.org/country. Accessed 7 January, 2023

WWF (2022). Congo Basin Forests. https://wwfeu.awsassets.panda.org/downloads/congo_forest_cc_final_13nov07.pdf. Accessed 15/01/2023

Yahya F, Lee CC (2023) The asymmetric effect of agriculturalization toward climate neutrality targets. J Environ Manag 328:116995. https://doi.org/10.1016/j.jenvman.2022.116995

Yang H, Shahzadi I, Hussain M (2021) USA carbon neutrality target: evaluating the role of environmentally adjusted multifactor productivity growth in limiting carbon emissions. J Environ Manag 298:113385. https://doi.org/10.1016/j.jenvman.2021.113385

Yasmeen R, Zhaohui C, Shah WUH, Kamal MA, Khan A (2022) Exploring the role of biomass energy consumption, ecological footprint through FDI and technological innovation in B&R economies: a simultaneous equation approach. Energy 244:122703. https://doi.org/10.1016/j.energy.2021.122703

You W, Zhang Y, Lee CC (2022) The dynamic impact of economic growth and economic complexity on CO_2 emissions: an advanced panel data estimation. Econ Anal Policy 73:112–128. https://doi.org/10.1016/j.eap.2021.11.004

Yufenyuy M, Nguetsop VF (2020) Climate variability and the emergence of malaria: case of Kumbo Central Sub-Division, North West Region. Cameroon Int J Global Sustain 4(1):104–127. https://doi.org/10.5296/ijgs.v4i1.17263

Yurtkuran S (2021) The effect of agriculture, renewable energy production, and globalization on CO_2 emissions in Turkey: a bootstrap ARDL approach. Renew Energy 171:1236–1245. https://doi.org/10.1016/j.renene.2021.03.009

Zhang Y, Long H, Tu S, Ge D, Ma L, Wang L (2019) Spatial identification of land use functions and their tradeoffs/synergies in China: Implications for sustainable land management. Ecol Indic 107:105550. https://doi.org/10.1016/j.ecolind.2019.105550

Zhong W, An H, Shen L, Dai T, Fang W, Gao X, Dong D (2017) Global pattern of the international fossil fuel trade: the evolution of communities. Energy 123:260–270. https://doi.org/10.1016/j.energy.2017.02.033

Zwane TT, Udimal TB, Pakmoni L (2023) Examining the drivers of agricultural carbon emissions in Africa: an application of FMOLS and DOLS approaches. Environ Sci Pollut Res 30(19):56542–56557. https://doi.org/10.1007/s11356-023-25173-8

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