Economic Change and Restructuring (2022) 55:2631–2661
https://doi.org/10.1007/s10644-022-09403-6

Responding to the environmental effects of remittances and trade liberalization in net-importing economies: the role of renewable energy in Sub-Saharan Africa

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Received: 9 July 2021 / Accepted: 4 April 2022 / Published online: 27 April 2022

Abstract

Little is currently known about how policy choices that seek to bridge the gap between low production capacity and growing consumption demands in developing economies impact the environment. To address this research gap, a quantile-based model is used to examine the impact of three policy-relevant variables on carbon dioxide (CO_2) emissions: international remittance inflows, trade liberalization, and renewable energy consumption. Territorial-based CO_2 emissions are used to explain the environmental effects of the variables when emissions are calculated solely on the basis of domestic production capacity. To consider if trade-induced consumption demands provide a better measure for assessing the environmental effects of the variable, consumption-based CO_2 emissions are used. The study focused on Sub-Saharan African countries with zero or net positive CO_2 emissions from trade. The results show, among other things, that remittances and trade liberalization increase CO_2 emissions irrespective of the accounting method. Trade, in particular, has a stronger effect through import-induced consumption activities. However, the effect is statistically insignificant for the lower quantile countries and statistically significant for the middle and upper quantile countries. Harnessing the potential of renewable energy to reduce CO_2 emissions should thus be a priority for policymakers in net-importing developing economies if production and consumption activities are to be created in less carbon-intensive ways.

Keywords Consumption-based CO_2 emissions · Remittances · Trade liberalization · Environment · Quantile regression · Sub-Saharan Africa

JEL Classification F18 · F24 · F64

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1 Introduction

In recent years, policy discussions have emphasized the importance of ensuring that derived benefits from economic integration remain sustainable. Among the key elements of the growing interest in this topic are the extensive policy measures considered in developing economies since the 1980s, ranging from liberalization, deregulation, and privatization of state-owned enterprises (SOEs) to the promotion of competitive industrial and service delivery sectors (Bhattacharyya 2019). According to the Brundtland Report (see WCED 1987), satisfying the sustainability condition would entail ensuring that derived economic benefits "meet the needs of the present without jeopardizing future generations' ability to meet their own needs" (Robert et al. 2005; Du Pisani 2006). Based on this condition, we examine whether remittance inflows and trade liberalization add to (or reduce) carbon dioxide (CO_2) emissions in Sub-Saharan African (SSA) economies. This goal aligns with Sustainable Development Goal 13 (SDG 13: Climate Action), which calls for identifying urgent policy responses to climate change challenges (Nerini et al. 2019).

Our interest in SSA countries is motivated by a number of conditions, among which are the recent policy choices in the region. One is the growing importance of remittances (i.e., money sent by migrants to families back home). According to the World Bank, remittance inflows to SSA region reached $4.8 billion in 2000 and $48 billion in 2019 (World Bank 2020). These figures represent 900 percent increase in remittance inflows to the region during the period. When the size of the economy is taken into account, these figures averaged 1.377 percent of GDP in 2000 and 2.768 percent of GDP in 2019. World Bank figures also reveal that remittance inflows to the region have since 2016 surpassed foreign direct investment (World Bank 2020). Similarly, trade liberalization policies have aided the integration of SSA economies into the global economy. Interventionist policies aimed at protecting the domestic market from foreign competition defined the trade environment until the end of the 1980s (Kassim 2015). Since 1991, the trade environment has significantly changed, and most SSA countries have defined policy paths for the import tariffs, export duties, and quantitative restrictions (Kassim 2015). According to the World Bank (2020), the share of SSA's exports and imports in its GDP has stayed relatively above the world average, with the 2019 estimate given as 53.075 percent. A more fascinating picture of the trade structure is created by the negative external balance on goods and services since 2013, which indicates that imports of goods and services have grown relatively faster than exports in the region (World Bank 2020). In general, recent policy initiatives have resulted in greater economic activity and resource inflows than outflows in the region.

While the growing economic activity in SSA economies may have been aided by remittance inflows and trade liberalization, environmental issues such as resource depletion and CO_2 emissions, which might limit long-term gains, need not be overlooked (see Shahbaz et al. 2017; Kolcava et al. 2019; Rahman et al. 2019; Adams and Opoku 2020; Karasoy 2021; Mahalik et al. 2021). One policy priority for SSA countries as they continue to pursue wide policy measures in the pursuit of greater economic integration benefits is to leverage policy options that mitigate induced environmental concerns. For instance, while free trade agreements foster economic integration, modern cattle farming methods could be encouraged among the SSA countries to counter the traditional approach that allows cattle to move about the land, thereby destroying the fields, causing clashes between the crop planters and herders, and is largely responsible for huge environmental damage. Among other options, we account for the role of renewable energy consumption. Renewable energy is considered the key to improving energy efficiency and reducing CO_2 emissions (Bhattacharya et al. 2017; Yu et al. 2020). Recognizing the need to reduce reliance on coal and fossil fuel-based energy sources and transition to modern renewable energy alternatives should thus be a priority for policymakers in SSA (UNECA-ACPC 2011; Nathaniel and Adeleye 2021). Taking advantage of the region's tremendous renewable energy potential will present a significant opportunity for achieving economic development goals and ensuring that the economic benefits of remittance inflows and trade liberalization policies are achieved in less carbon-intensive ways.

A review of the literature finds two gaps in related studies. First, there is still limited panel evidence on the impact of trade liberalization and remittance inflows on CO_2 emissions in net-importing economies. Previous studies have not considered that net-importing and net-exporting economies may require different policy considerations. As a result, countries have been selected for panel analysis based on either geographic or income classifications. Within a geographical region and in various income groups, countries show different levels of dependence on trade. There is no doubt that varied trade and economic integration targets among countries and regions would also produce varied environmental challenges and the need to consider how different policy choices apply under these economic conditions. Second, previous studies have relied on CO_2 emissions calculated solely on the basis of territorial production capacity, without considering the embodied CO_2 emissions in trade activities. This could limit the appropriateness of policy selections targeting CO_2 emissions mitigation in net-importing economies. In view of these considerations, this study fills a gap in the literature by extending the Environmental Kuznets Curve (EKC) equation to account for the role of remittance inflows, trade liberalization, and renewable energy in explaining environmental sustainability challenges in a selection of SSA countries.

To add to the literature, this study uses disaggregated data on CO_2 emissions: territorial-based and consumption-based CO_2 emissions. This step is intended to explain the environmental implications of trade liberation, remittances, and renewable energy when CO_2 emissions are calculated on the basis of activities within a country's territory and considers whether CO_2 embedded in trade-induced consumption activities provides a better measure to understand the environmental impact of the variables in the SSA countries. As shown in the Global Carbon Budget (GCB) compiled by Friedlingstein et al. (2019), SSA countries are primarily net importers of CO_2, suggesting that formulating policies based on trends in territorial-based CO_2 emissions may result in restricted policy options. As a result, this analysis focuses more on explaining trade-adjusted CO_2 emissions in SSA economies. Trade-adjusted

CO2 emissions accounts for the impact of consumption demands by subtracting emissions embodied in exports from territorial-based emissions and adding emissions embodied in imports (Peters 2008; Turker et al. 2020). As expected, GCB shows that apart from South Africa and Nigeria which are net exporters of CO_2, the remaining countries in the region are either net importers of CO_2 or have zero net transfer of CO_2. This condition underscores the extent to which SSA economies rely on overseas production to meet home demand, as well as the necessity to investigate whether their dependence on trade contributes to their environmental impacts, in the form of CO_2 emissions.

Methodologically, this study uses a panel estimation approach, the Method of Moments Quantile Regression approach (MM-QR), recently proposed by Machado and Silva (2019), that is able to account for individual and distributional heterogeneous characteristics existing across the selected SSA countries. Hence, this study considers the possibility that the drivers of domestic production activity and consumption demands may have varying environmental effects across the conditional distribution of CO_2 emissions. For example, remittance inflows and trade liberalization are likely to have a greater impact on environmental policy choices in countries with more liberalized trade policy targets and greater openness to economic integration. This is because these countries attract more remittances and engage in more trading activities. In addition, given the heterogeneity in the sizes of the economies in the SSA region, the EKC hypothesis may produce varying results across the quantile distribution of CO_2 emissions in the region. This is one of the few studies to investigate the distributional effects of remittance inflows on trade-adjusted CO_2 emissions in developing economies. From a policy standpoint, the findings of this study would support environmental policy choices in Africa and other developing economies.

The remainder of this paper is divided into five sections: literature review in Sect. 2, data presentation and study methodology in Sect. 3, results presentation and discussion in Sect. 4, and conclusion and policy implications in Sect. 5.

2 Theoretical underpinnings and related existing empirical literature

In this section, the theoretical underpinnings of the environmental impact of remittance inflows, trade, and renewable energy, as well as the findings of related existing empirical studies, are reviewed.

2.1 Remittances and CO_2 emissions

There are several mechanisms (i.e., channels of effects) by which remittance-induced income affect CO_2 emissions. Remittances, as an important significant source of income for households, may encourage increased consumption and savings in the economy (Brown et al. 2020; Elbatanony et al. 2021; Jiang et al. 2021). This implies that an increase in remittances may translate into increased demand for household goods including energy intensive gadgets, e.g., new vehicles, electrical appliances, and consequently more CO_2 emissions (Brown et al. 2020; Elbatanony et al. 2021; Jiang et al. 2021). Because most household goods are manufactured in the industrial sector, an increase in aggregate consumption caused by remittances will also result in an increase in industrial production (Adeleye et al. (2021). According to Fischedick et al. (2014), the rise in CO_2 emissions is strongly linked to industrial activity. Brown et al. (2020) and Jiang et al. (2021) add that a remittance-induced income may encourage households to deposit their surplus income with commercial banks in expectation for interest. This further increases the banking sector's deposit mobilization and credit allocation activities, as well as private-sector economic activity, such as the construction of new plants and increased industrial energy demand. Acheampong (2019) show in this context that increased domestic credit to the private sector has the potential to induce carbon-intensive activities in Sub-Saharan African economies. From a different perspective, Elbatanony et al. (2021) argued that the increase in income generated by remittances may encourage less carbon-intensive human activities and increase in demand for cleaner gadgets that households might not have been able to afford otherwise. Also, by inducing the savings habit of household and more financial resources for credit to firms, increase in remittance inflow into the economy may as well assist firms in adopting techniques that are less carbon-intensive through newer technologies (Elbatanony et al. 2021).

A review of related empirical studies shows that the impact of remittances on CO_2 emissions varies among countries. Over the period 1982–2014, remittances induced CO_2 emissions in Sri Lanka, Pakistan and Bangladesh but had no significant environmental impact in China (Rahman et al. 2019). Positive impact on CO_2 emissions was identified in the Philippines from 1977 to 2016 (Karasoy 2021), in India from 1978 to 2014 (Mahalik et al. 2021), and in Australia from 1972Q1 to 2014Q4 (Jiang et al. 2021). Similarly, from a different sample spanning the years 1986–2016, Khan et al. (2020a) found that remittances helped to reduce CO_2 emissions in India while increasing CO_2 emissions in Russia and Brazil and having no significant mitigation impact in South Africa. For a panel of five Asian countries, Wang et al. (2021) showed that remittances supported CO_2 mitigation strategies in the economies during the period 1980–2016. Yang et al. (2020) showed that remittances have an increasing impact on CO_2 emissions from a global sample of 97 countries from 1990 to 2016. Also, with a global sample of 93 countries, Usman and Jahanger (2021) found significant distributional heterogeneity in the impact of remittances on CO_2 emissions. The findings showed that during the period 1990–2016, remittances induced CO_2 emissions in countries at the lower quantiles of CO_2 distribution. For countries at the upper quantiles, the empirical estimates showed significant negative impact on CO_2 emissions. Overall, these findings support the conclusion that the impact of remittances on CO_2 emissions could depend on a variety of factors. Thus, for net importing economies, understanding the relationship between the variables would aid in the formulation of appropriate SDG policy framework.

2.2 Trade liberalization and CO_2 emissions

Environmental economics literature identifies three major mechanisms by which trade liberalization can affect CO_2 emissions: scale, composition, and technique effects (Qirjo and Christopherson 2016; Sannassee and Seetanah. 2016; Xu et al. 2020). Keeping all other conditions constant, the scale effect explains the increase in CO_2 emissions by observing that trade liberalization scales up economic activities, resulting in increased demand for energy-intensive production and consumption activities (Sannassee and Seetanah 2016). The composition effect focuses on the role of trade liberalization in shifting the production structure in favor of capital-intensive goods, which are also generally pollution-intensive (Sannassee and Seetanah 2016). The technique effect explains that trade liberalization makes cleaner environmental technologies more accessible to developing countries while also increasing per capita income to support their demand for cleaner consumption pattern (Sannassee and Seetanah 2016).

Recent discussions on the environmental impact of trade liberalization have centered on developing countries, with the goal of improving our understanding of their vulnerability to environmental burden transfer. According to one school of thought, trade liberalization will result in developing economies becoming havens for pollution-intensive goods from industrialized nations (Copeland and Taylor 1994). This is referred to as the *pollution haven* hypothesis, which is centered on the composition effect. According to this hypothesis, developing countries are presumed to be more concerned with solving socioeconomic problems than environmental problems and lacks strong regulatory framework and institutions to control the transfer of pollution-intensive goods from more environmentally concerned developed countries into their economies (Copeland and Taylor 1994; Duan and Jiang 2021). A number of studies in the literature have validated the pollution haven hypothesized impact of trade liberalization (see, e.g., Sannassee and Seetanah 2016 for Mauritius; Solarin et al. 2017 for Ghana; Vural 2020 for a panel of eight Sub-Saharan African economies; Duan and Jiang 2021 for low-income and high-income economies). Another school of thought contends that trade liberalization through the transfer of low-carbon technologies (e.g., renewable energy technologies) can lead to efficient energy usage and hence cleaner consumption and production patterns (Duan and Jiang 2021).It is from this perspective that a number of recent studies argue that multinational companies from the more environmentally conscious developed countries, create "pollution halos", which lead to a win–win situation for both firms and host developing countries (see, e.g., Chen et al. 2019 for the case of vehicle trade between the USA and Mexico; Wang et al. 2019 for Beijing neighboring cities; Xu et al. 2020 for China).

2.3 Renewable energy use and CO_2 emissions

Energy is required to meet basic human needs (such as lighting, cooking, mobility, and communication) as well as to carry out production activities (Santika et al.

2019; Srivastav 2021). Renewable energy sources, such as biomass, wind, sun, hydropower, and geothermal power, can individually provide a massive and regularly replenished supply of energy with no negative environmental impact, unlike the combustion of fossil fuels (coal, oil, and gas) which produces CO_2 emissions (Bhattacharya et al. 2017; Destek and Aslan 2020). As a result, policymakers anticipate that substituting renewable energy sources for fossil fuels would result in significant reduction in CO_2 emissions. Empirically, recent studies have confirmed the carbon-mitigating effect of renewable energy. For example, Hasanov et al. (2021) show that increasing renewable energy use reduces CO_2 emissions in the BRICS countries. Similar findings were reported by Zafar et al. (2020), Adedoyin et al. (2021), and Destek and Aslan (2020) for OECD, West African, and G7 countries, respectively. However, Bhattacharya et al. (2017) found no evidence of a significant negative relationship between renewable energy and CO_2 emissions in the Middle East and North Africa. Similar findings by Adedoyin et al. (2021) show the same condition exists in Southern Africa. In another study, Akram et al (2020) found that the environmental impact of renewable energy in developing countries could be heterogeneous across different quantile distribution of CO_2 emissions. The study used a panel of 66 developing countries from 1990 to 2014 to show that using renewable energy reduces CO_2 emissions in all quantiles, but the mitigation effect is larger in countries at the lower quantiles.

In light of the foregoing discussions, we investigate three policy-relevant questions. First, do remittances impose an environmental burden by increasing territorial and consumption related CO_2 emission inventories of developing net importing economies? Second, does trade liberalization promote environmental burden transfer in the form of inducing CO_2 emissions embedded in trade of developing economies? Third, can developing net importing economies rely on renewable energy to respond to environmental challenges posed by global economic integration? By providing empirical answers to these questions, this study contributes to the growing interest in the drivers of cross-border pollution and transfer, and the role of trade liberalization. Liddle (2018) and Khan et al. (2020b) are among recent studies that attempted to explain trade-adjusted CO_2 emissions. However, the authors relied on sampled countries, which may not have adequately explained the specific case of net importing developing economies. To make a significant contribution to the literature, this study focuses on net importing economies in the Sub-Saharan African region, where territorial and consumption activities significantly rely on imports. Furthermore, the impact of remittances is accounted for which is a major source of financial inflow that was not empirically addressed by Liddle (2018) and Khan et al. (2020b) as well as the role of renewable energy use in responding to pollution challenges.

3 Model specification, data, and method of estimation

3.1 Model specification

Carbon emissions are driven by a number of fundamental factors. Key among them is economic growth (Yang et al. 2021). According to the findings of

Grossman and Krueger (1991) emissions tend to rise with income at the early stages of development. Grossman and Krueger (1991) also observed negative income-emissions relationship at later stages of development when certain levels of income have been attained. Based on these findings, recent studies have modelled an inverted relationship between economic indicators and CO_2 emissions under a hypothesis generally known as the Environmental Kuznets Curve (EKC) framework (see Acheampong 2019; Akram et al. 2020; Vural 2020). Empirical tests of the inverted U-shaped income- pollution relationship have however produced varied results. For instance, Acheampong (2019) show that the EKC curve is not valid in Sub-Saharan Africa, Xu et al. (2020) show a U-shaped curve for China while Akram et al. (2020) show a valid inverted U-shaped curve across different quantile distribution of CO_2 emissions using a panel of 66 developing economies. In this study, the EKC definition is extended to specify the following equation for empirical analysis:

$$\ln CO2_{i,t} = \beta_0 + \beta_1 \ln Egr_{i,t} + \beta_2 \ln EgrSQ_{i,t} + \beta_4 \ln Remit_{i,t} + \beta_5 \ln Trd_{i,t} + \beta_5 \ln Ren_{i,t} + \varepsilon_{i,t} \tag{1}$$

where CO2 stands for carbon dioxide emissions measured in per capita terms which in this study is defined in two forms: territory-based CO_2 emissions (TerCO2) and trade-based CO_2 emissions (TrdCO2). Overall, the following empirical formulation for investigation is derived:

$$\ln TerCO2_{i,t} = \phi_0 + \phi_1 \ln Egr_{i,t} + \phi_2 \ln EgrSQ_{i,t} + \phi_3 \ln Remit_{i,t} + \phi_4 \ln Trd_{i,t} + \phi_5 \ln Ren_{i,t} + v_{i,t} \tag{2}$$

$$\ln TrdCO2_{i,t} = \eta_0 + \eta_1 \ln Egr_{i,t} + \eta_2 \ln EgrSQ_{i,t} + \eta_3 \ln Remit_{i,t} + \eta_4 \ln Trd_{i,t} + \eta_5 \ln Ren_{i,t} + s_{i,t} \tag{3}$$

where *Egr* is for Gross Domestic Product (GDP) per capita representing economic growth. *EgrSQ* is the square of GDP per capita. *Remit* is for received personal remittances. *Trd* is for trade openness measured based on three classifications; total trade (exports + imports), exports of goods and services and imports of goods and services. *Ren* is for the proportion of renewable energy in the total primary energy use. ϕ_0 and η_0 are the intercept coefficients of the functional relationship, $\phi_1 \ldots, \phi_5$ and $\eta_1, \ldots, \eta_5$ are the coefficients of the explanatory variables which form the basis for explaining the respective impacts of the variables on CO_2 emissions. Other parameters in the functional relationship include the error terms v, s, the cross-sectional country index i and the time index t,which defines the years covered. The inverted U-shaped curve of the EKC hypothesis is valid if $\phi_1, \eta_1 > 0$ and $\phi_2, \eta_2 < 0$. Also, we have inserted "ln" to indicate that all the variables are defined in their natural logarithmic form. Using the variables in natural logarithmic form gives the estimates of the parameters of the functional relationship as elasticities and thus aid interpretation and policy formulation.

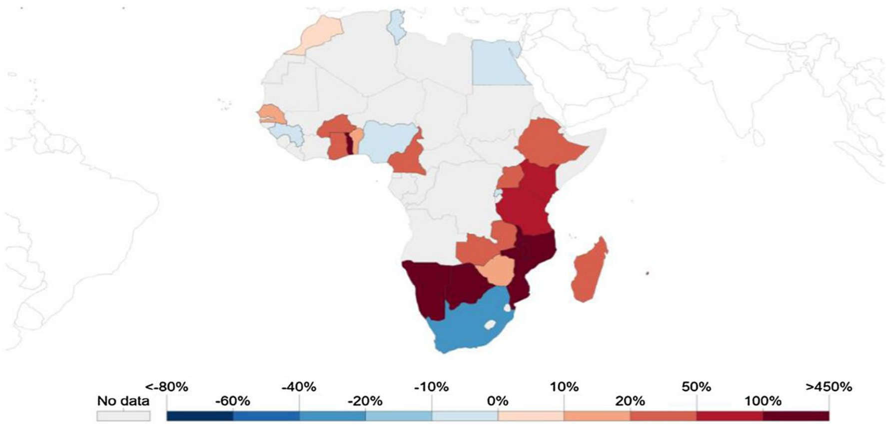

Fig. 1 Distribution of trade embodied CO_2 emissions in Sub-Saharan African countries in 2018. Positive values (shaded RED) represent net importers of CO_2 emissions while Negative Values (shaded BLUE) represent net exporters of CO_2 emissions. Source: Compilation of Our World in Data: https://ourworldindata.org/grapher/share-co2-embedded-in-trade

3.2 Data

This study focuses on explaining CO_2 emissions in Sub-Saharan African countries based on two accounting perspectives: territorial and consumption. Emissions data compiled using a territorial-based method calculates those emissions that occur within a country's borders or within the borders of a country's jurisdiction (Peters et al. 2012). Such emissions are compiled based on domestic production of goods and services, without taking into consideration whether they are transferred to other countries via international trade. The consumption perspective considers those emissions that result from the consumption of goods and services within a country, regardless of the geographic location where these goods and services are produced (Peters et al. 2012). Comparatively, consumption-based perspective calculates CO_2 emissions by adding net emissions from international trade—that is, subtracting emissions embodied in exports from territorial emissions and adding emissions embodied in imports.[1]

The Global Carbon Budget provides limited data availability on trade-adjusted CO_2 emissions for Sub-Saharan African countries (see Fig. 1). Selected countries for this study are those where trade-adjusted CO_2 emissions are equal or higher than territorial-based CO_2 emissions (i.e., countries that are net importers of CO_2 emissions and countries with zero net transfer of CO_2 emissions). Based on this selection criterion, net exporters of CO_2 emissions in the region, including Nigeria and South Africa, were excluded at the panel construction stage.

[1] Trade-adjusted (Consumption-based) CO_2 emissions = emissions embodied in production within a country's territorial jurisdiction minus (–) emissions embodied in exports plus (+) emissions embodied in imports (Peters et al. 2012).

Table 1 Definition of variables, data sources, and descriptive statistics

Panel A: Definition of variables and sources of data

Variable	Symbol	Definition and measurement	Data source
Territorial-based CO_2 emissions	TerCO2	CO_2 emissions embodied in domestic production (million tons per year)	Global carbon budget (Friedlingstein et al. 2019)
Trade-adjusted CO_2 emissions	TrdCO2	Consumption-based CO_2 emissions (million tons per year)	Global carbon budget (Friedlingstein et al. 2019)
Economic growth	Egr	GDP per capita (constant 2010 US$)	WDI, World Bank
Renewables in energy mix	Ren	Proportion of renewable energy consumption in total final energy consumption	1995–2015 WDI, World Bank; 2016 &2017 SDG Indicators Database, United Nations
Remittances	Remit	Remittances received (% of GDP)	WDI, World Bank
Total trade	Trd-Total	Trade, Total (Imports + Exports as % of GDP)	WDI, World Bank
Imports trade	Trd-Import	Imports of goods and services (% of GDP)	WDI, World Bank
Trd-Exports	Trd-Export	Exports of goods and services (% of GDP)	WDI, World Bank

Panel B: Descriptive statistics

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque–Bera	Probability	Observations
TerCO2	0.414	0.229	3.280	0.045	0.569	2.750	10.381	1380.222	0.000	391
TrdCO2	0.709	0.335	8.415	0.055	1.248	3.893	19.722	5543.371	0.000	391
Egr	1350.433	815.874	7864.253	215.166	1599.183	2.481	8.135	830.737	0.000	391
Ren	71.929	79.079	95.971	25.365	19.860	−0.989	2.727	64.907	0.000	391
Remit	1.962	0.960	10.711	0.000	2.404	2.001	6.476	457.872	0.000	391
Trd-Total	62.716	58.597	125.478	23.981	22.321	0.545	2.468	23.979	0.000	391
Trd-Import	26.672	24.898	61.523	5.151	11.964	0.637	2.825	26.933	0.000	391
Trd-Export	36.044	33.570	80.834	13.172	12.351	0.948	3.779	68.461	0.000	391

To express TerCO2 and TrdCO2 in per capita terms, we divided million tons of CO_2 emissions by the total population

Source: Authors' Computations

Table 2 Cross-sectional dependence test

Variable	CD-test	p-value	Average joint	Mean ρ	Mean abs(ρ)
lnTerCO2	23.235***	0.000	23.00	0.42	0.53
lnTrdCO2	30.921***	0.000	23.00	0.55	0.60
lnEgr	38.182***	0.000	23.00	0.68	0.69
lnEgrSQ	38.334***	0.000	23.00	0.69	0.70
lnRemit	4.085***	0.000	23.00	0.07	0.38
lnTrd-Total	7.320***	0.000	23.00	0.13	0.35
lnTrd-Import	2.328**	0.020	23.00	0.04	0.34
lnTrd-Export	9.845***	0.000	23.00	0.18	0.33
lnRen	27.214***	0.000	23.00	0.49	0.54

Under the null hypothesis of cross-sectional independence, CD ~ N(0,1); ***$p<0.01$, **$p<0.05$, *$p<0.1$; p-values close to zero indicate data are correlated across panel groups

Source: Authors' Computations using STATA 16

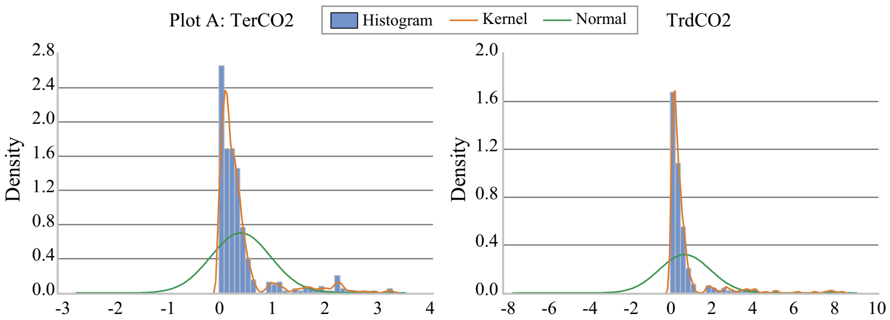

Fig. 2 Histogram and Gaussian Kernel density plots (Plot A: TerCO2; Plot B: TrdCO2)

Data availability on other variables of interest is also considered given the functional relationship established in Eqs. 2 and 3. Overall, a balanced panel consisting of seventeen (17) countries is constructed for this study, covering the period 1995–2017 (23 years and 391 observations). The countries are Benin, Botswana, Burkina Faso, Cameroon, Côte d'Ivoire, Ghana, Guinea, Kenya, Madagascar, Malawi, Mozambique, Namibia, Rwanda, Senegal, Tanzania, Togo, and Uganda. Table 1 summarizes the definitions and data sources for all the variables.

Some descriptive statistics on the variables are summarized in Table 2. Of interest are the probability values of the Jarque–Bera test which show that TerCO2 and TrdCO2 and the explanatory variables of interest are not normally distributed. Figure 2 uses histogram and Kernel density plots to describe the distribution of TerCO2 and TrdCO2. The plots reveal for each of the two variables, skewed and highly peaked distribution that deviates significantly from normal (symmetric) distribution.

3.3 Methods of estimation

The estimation process is covered by taking the following discussed steps:

3.3.1 Cross-sectional dependence (CSD)

Strong linkages exists among SSA countries, making it highly possible that variables explaining trends in economic, social, political and even environmental conditions in the region will have cross-sectional dependencies.[2] Therefore, we perform Pesaran (2004) test for cross-sectional dependence. The CSD statistics is defined as follows:

$$CSD = \sqrt{\frac{2T}{N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}} \tag{4}$$

where T defines the period of study which in the case of this study covers 1995–2017 (23 years), N defines the number of cross-sectional units (17 countries) and $\hat{\rho}_{ij}$ defines the correlation among the errors between cross sections. The CSD statistic is estimated under the null hypothesis of no cross-sectional dependence.

3.3.2 Panel unit root tests

To ascertain the unit root properties of the variables, we use Pesaran (2007) panel unit root test, applied in the presence of cross-sectional dependence. This test augments the Dickey–Fuller regression to account for cross-sectional dependence. The cross-sectionally augmented Dickey–Fuller (CADF) test is based on the following equation:

$$\Delta y_{i,t} = \alpha_i + \rho_i * y_{i,t-1} + b\overline{y}_{t-1} + b_1 \Delta \overline{y}_t + \varepsilon_{i,t} \tag{5}$$

In which, $\overline{\overline{y_t}}$ is the average of y at time t for all N obsrvations. The CADF equation is performed for each cross-sectional unit, and then average is taken over all the cross sections and the resulting test statistic is calculated as follows:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} CADF_i \tag{6}$$

[2] SSA economies have certain commonness which may bias analysis if not controlled. To mention a few, the region boasts of common trade terms via the African Continental Free Trade Area. In addition, the region exhibits Common Currency Area of which there are two existing regional currency unions – the West African CFA franc and the Central African CFA franc, and lastly, the region has a common strategy in combating the problem of climate change as contained in "African Union Strategy on Climate Change" www.wedocs.unep.org.

where $CADF_i$ is the statistic obtained from the CADF regression as expressed in Eq. (5). Pesaran (2007) provides additional statistic, CIPS-TR (i.e., the truncated version of CIPS statistic):

$$CIPS - TR = \frac{1}{N}\sum_{i=1}^{N} CADF_i^{*} \tag{7}$$

where $CADF_i^{*}$ indicates that the regression estimates from Eq. (5) are truncated to limit the influence of extreme outcomes that may arise when the size of T is not sufficiently large.

3.3.3 Cointegration tests

We follow Engle-Granger two-step procedure for testing the existence of cointegration among variables. First, we implement the following equation:

$$Y_{it} = \alpha_i + \beta_i X_{it} + \varepsilon_{it} \text{for} i = 1, 2, 3, ..., N \text{and} t = 1, 2, 3, ..., T \tag{8}$$

where Y_{it} represent measures of CO_2 emissions and X_{it} represent selected explanatory variables of interest. Based on Eq. (8), N vectors of residuals are extracted.[3] In the second step, we applied Pesaran (2007) unit root tests on the extracted residuals to test for stationarity in the presence of cross-sectional dependence. This step is based on the following regression equation:

$$\varepsilon_{it} = \tau_i \varepsilon_{it-1} + \psi_{it} \tag{9}$$

If the residuals are stationary, we conclude that Y_{it} and X_{it} are cointegrated but if the residuals are not stationary, we conclude that no cointegration exist among the variables (Sharma and Bardhan, 2016). We provide further evidence using Westerlund (2007) error correction-based cointegration test, which is also robust and reliable in the presence of CSD. The error correction equation takes the form:

$$\Delta Y_{i,t} = \mu_i^{\prime} d_t + \omega_i \left(Y_{i,t-1} - \beta_i^{\prime} X_{i,t-1} \right) + \sum_{j=1}^{k} \varnothing_{ij} \Delta Y_{i,t-j} + \sum_{j=1}^{k} \gamma_{ij} \Delta X_{i,t-j} + \varepsilon_{i,t} \tag{10}$$

In Eq. (10), ω_i is the coefficient of the error correction term providing the speed of correction towards equilibrium while Δ is the first difference operator. Four (4) test statistics can be derived from the equation:

$$G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{\widehat{\omega}_i}{se(\widehat{\omega}_i)} \tag{11}$$

[3] Regress CO_2 emissions on the explanatory variables for each cross-sectional unit, extract the residuals and sort them into NT*1 dimension.

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\hat{\omega}_i}{1-\sum_{j=1}^{k}\omega_{ij}} \tag{12}$$

$$P_t = \frac{\hat{\omega}}{se(\hat{\omega})} \tag{13}$$

$$P_a = T\hat{\omega} \tag{14}$$

The G_t defined in Eq. (11) and G_a presented in Eq. (12) provide basis for testing the existence of cointegration in at least one cross-sectional unit. The P_t defined in Eq. (13) and P_a defined in Eq. (14) provide statistics for the testing of cointegration in the entire panel. Statistical significance of one or both panel statistics will suggest that the null hypothesis of no cointegration in the entire panel is rejected.

3.3.4 Estimation of elasticities

To derive baseline estimates for various specifications of Eqs. (2 and 3), we use the Driscoll–Kraay (DK) regression, which uses standard errors that are robust to general form of cross-sectional and temporal dependence (Driscoll and Kraay 1998). As part of the preliminary steps for implementing DK regression, we use the Hausman (1978) test to ascertain whether the model specifications exhibit random effects (RE) or fixed effects (heterogeneity).[4] The DK regression approach uses the OLS/weighted least squares[5] and fixed effects (within) regression and computes spatial correlation consistent standard errors for linear panel models. These estimators correct the standard errors of the coefficient estimates for possible dependence (Hoechle 2006).

The major weakness of DK regression technique is that it only models the conditional mean of the dependent variable. To model other aspects of the conditional distribution of TerCO2 and TrdCO2, this study employs the method of moments quantile regression (MM-QR) approach for handling fixed effects in panel quantile models proposed by Machado and Silva (2019). Using the MM-QR estimator, the impact of remittances, trade and renewable energy on lower, median and upper distributions of TerCO2 and TrdCO2 in Sub-Saharan Africa is uncovered. As with other panel quantile regression techniques (see Canay 2011; Galvao 2011), MM-QR estimator provides robust and valid estimates without requiring strong distributional assumptions. However, unlike the procedure in Canay (2011) and Galvao (2011), the MM-QR algorithm generates regression quantiles based on the conditional location-scale shift model, allowing for the individual effects to influence the whole

[4] We engaged this approach because the Driscoll-Kraay technique allows for either pooling of the data (recognises homogeneity) using the ordinary least squares (OLS) approach or recognising the heterogeneities of the cross-sectional units using fixed effects. Therefore, we deployed the Hausman (1978) test to ascertain the most appropriate routine to deploy.

[5] Weighted least squares.

distribution. This makes MM-QR more robust and the preferred quantile regression technique in recent literature. The conditional quantile $Q_Y(\tau|X)$ estimation of the location-scale variant model takes the following general specification:

$$Q_Y\left(\tau|X_{it}\right) = (\alpha_i + \delta_i qi) + X_{it}^{'}\beta + Z_{it}^{'}\gamma q(\tau) \tag{15}$$

$X_{it}^{'}$ in Eq. (15) is a vector of explanatory variables which in this present study comprise economic growth (*Egr*), remittances (*Remit*), Trade (*Trd*), and renewable energy (*Ren*). $Q_Y\left(\tau|X_{it}\right)$ represents the quantile distribution of the dependent variable (in this study, TerCO2 and TrdCO2) conditional on the location of explanatory variable (X_{it}). $\alpha_i(\tau) = \alpha_i + \delta_i q(\tau)$ is the scalar coefficient of the quantile-τ fixed effect for individual i, or the distributional effect at τ. $q(\tau)$ is the $\tau - th$ quantile derived from the following optimization function:

$$\min_q \sum_i \sum_t \rho_\tau\left(\widehat{R}_{it} - \left(\widehat{\delta}_i + Z_{it}^{'}\widehat{\gamma}\right)q\right) \tag{16}$$

In which, $\rho_\tau(A) = (\tau - 1)AI\{A \leq 0\} + \tau AI\{A > 0\}$ provides the check-function. Based on the MM-QR model in Eq. (15) and the functional relationship in Eqs. (2 and 3), we specify the following quantile-based approach that reflects the SDG components for this empirical investigation:

$$\begin{aligned} Q_{\ln TerCO2_{i,t}}[\tau|\alpha_i, v_{it}, X_{i,t}] =& \alpha_{i\tau} + \phi_{1\tau}\ln Egr_{i,t} + \phi_{2\tau}\ln EgrSQ_{i,t} \\ &+ \phi_{3\tau}\ln Remit_{i,t} + \phi_{4\tau}\ln Trd_{i,t} + \phi_{5\tau}\ln Ren_{i,t} + v_{i,t} \end{aligned} \tag{17}$$

$$\begin{aligned} Q_{\ln TrdCO2_{i,t}}[\tau|\alpha_i, s_{it}, X_{i,t}] =& \alpha_{i\tau} + \eta_{1\tau}\ln Egr_{i,t} + \eta_{2\tau}\ln EgrSQ_{i,t} \\ &+ \eta_{3\tau}\ln Remit_{i,t} + \eta_{4\tau}\ln Trd_{i,t} + \eta_{5\tau}\ln Ren_{i,t} + s_{i,t} \end{aligned} \tag{18}$$

4 Empirical results and discussion

This section begins with a number of preliminary tests to check for cross-sectional dependence (see results reported in Table 2), unit root properties of the variables (see results reported in Table 3), cointegration among the variables (see results reported in Table 4), check for fixed effects in the model specification (see results reported in Table 5), the baseline model using Driscoll–Kraay panel fixed-effects regression (see results in Table 6) and the distributional impact analyses from MM-QR panel quantile regression technique (see results reported in Tables 7). Tables 6 and 7 are divided into two panels: A and B. Estimates in Panel A explain changes in territorial-based CO_2 emissions while estimates in Panel B explain trade-adjusted CO_2 emissions. Three sections of quantiles are reported in Table 7: the lower quantile (qtile_5th, qtile_10th, and qtile_25th); the median quantile (qtile_50th); and the upper quantile (qtile_75th, qtile_90th, and qtile_95th).

Table 3 Cross-sectional augmented panel unit root tests

Variables	CIPS				CIPS-TR				
	Level I(0)		1st difference I(1)		Level I(0)		1st difference I(1)		
	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend	Constant	Constant and trend	Decision
lnTerCO2	−1.753	−2.128	−4.518***	−4.330***	−1.745	−2.076	−4.468***	−4.285***	I(1)
lnTrdCO2	−1.529	−2.056	−4.542***	−4.422***	−1.529	−2.056	−4.455***	−4.376***	I(1)
lnEgr	−1.207	−1.382	−3.493***	−3.801***	−1.207	−1.382	−3.493***	−3.801***	I(1)
lnEgrSQ	−1.128	−1.606	−3.510***	−3.796***	−1.128	−1.606	−3.510***	−3.796***	I(1)
lnRemit	−1.523	−1.808	−4.039***	−4.148***	−1.523	−1.808	−4.004***	−4.128***	I(1)
lnTrd-Total	−1.796	−2.267	−3.886***	−4.160***	−1.796	−2.267	−3.876***	−4.130***	I(1)
lnTrd-Export	−1.942	−2.164	−3.561***	−3.480***	−1.942	−2.164	−3.561***	−3.480***	I(1)
lnTrd-Import	−2.196	−2.331	−4.586***	−4.592***	−2.196	−2.331	−4.469***	−4.502***	I(1)
lnRen	1.885	−1.998	−4.263***	−4.769***	1.885	−1.998	−4.263***	−4.769***	I(1)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$ indicate significance at 1, 5% and 10% respectively

Source: Authors' Computations using Eviews 12

Table 4 Panel cointegration tests

Model specifications	Residual based (Engle-Granger two-step)		Error correction-based (Westerlund 2007)			
	Constant only (p-value)	CIPS-TR Constant and Trend (p-value)	Gt (Robust p-Value)	Ga (Robust p-Value)	Pt (Robust p-Value)	Pa (Robust p-Value)
1.lnTerCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Total, lnRen	−3.6450*** (<0.01)	−3.4185*** (<0.01)	−3.035** (0.030)	−8.157* (0.070)	−12.614*** (0.010)	−8.825*** (0.020)
2.lnTerCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Export, lnRen	−3.835*** (<0.01)	−3.640*** (<0.01)	−2.882 (0.020)	−8.117 (0.010)	−12.900*** (0.010)	−8.873*** (0.010)
3.lnTerCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Import, lnRen	−3.646*** (<0.01)	−3.485*** (<0.01)	−3.089** (0.030)	−8.554** (0.050)	−12.284*** (0.010)	−8.857*** (0.010)
4.lnTerCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Export, lnTrd-Import, lnRen	−3.739*** (<0.01)	−3.587*** (<0.01)	−2.862* (0.090)	−7.080** (0.050)	−11.556** (0.050)	−7.247** (0.020)
5.lnTrdCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Total, lnRen	−3.580*** (<0.01)	−3.628*** (<0.01)	−3.857*** (0.010)	−10.208*** (0.000)	−14.658** (0.030)	−11.310*** (0.010)
6.lnTrdCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Export, lnRen	−3.302*** (<0.01)	−3.305*** (<0.01)	−3.452*** (0.000)	−10.331*** (0.000)	−13.741** (0.020)	−11.799*** (0.010)
7.lnTrdCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Import, lnRen	−3.473*** (<0.01)	−3.558*** (<0.01)	−4.045*** (0.000)	−10.702*** (0.000)	−15.685*** (0.000)	−11.212*** (0.000)
8.lnTrdCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Export, lnTrd-Import, lnRen	−3.301*** (<0.01)	−3.367*** (<0.01)	−3.599*** (0.010)	−8.036*** (0.000)	−15.204*** (0.000)	−8.909** (0.030)

The CIPS-TR statistics test the significance of the residuals at the level form. Robust p-Values are from 100 bootstrap replications of the critical values

Source: Authors' Computations using Eviews 12 for CIPS-TR test and STATA 16 for Westerlund (2007) test

*$p<0.1$, **$p<0.05$, ***$p<0.01$ Statistically significance indicates a rejection of the null hypothesis of no cointegration

Table 5 Estimates from Hausman test

	Model specification	chi2(6)	Prob > chi2
1	lnTerCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Total, lnRen	12.17 **	0.033
2	lnTerCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Export, lnRen	11.52 **	0.042
3	lnTerCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Import, lnRen	12.82 **	0.028
4	lnTerCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Export, lnTrd-Import, lnRen	12.18 **	0.050
5	lnTrdCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Total, lnRen	21.27 ***	0.001
6	lnTrdCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Export, lnRen	22.12 ***	0.001
7	lnTrdCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Import, lnRen	17.83 ***	0.003
8	lnTrdCO2, lnEgr, lnEgrSQ, lnRemit, lnTrd-Export, lnTrd-Import, lnRen	19.89 ***	0.003

Source: Authors' Computations using STATA 16

4.1 Results from preliminary tests

The results from Pesaran (2004) CSD test presented in Table 2 show evidence of cross-sectional dependence for each variable at 1% significance level. Consequently, panel unit root tests by Pesaran (2007) are used to determine the stationarity properties of the variables in the presence of cross-sectional dependence. As shown in Table 3, all the variables are stationary only at the first difference, even when the test statistics are truncated to limit the influence of extreme values. Hence, we conclude that all the variables are integrated of order one, I(1). Next, we test for cointegration among the variables using a residual-based cointegration technique that follows the Engle-Granger two-step procedure. The results show that the derived residuals (ε_{it}) in each of the model specifications are stationary at the level form. This suggests that a stable long-run relationship exists among the variables. For robustness, we also applied the Westerlund (2007) error correction-based test. The results in Table 4 show that the p-values for the panel test statistics (Pt and Pa) are not greater than 5% (i.e., 0.05), which implies that the null hypothesis of no cointegration is rejected for the entire panel. The null hypothesis is also rejected for the cross-sectional units, as the p-values for Gt and Ga statistics indicate. As part of the preliminary tests, we performed the Hausman test, and the results are presented in Table 5. They show a significant systematic difference in the coefficients, indicating that a panel fixed effects model will be appropriate for investigating the specifications under study.

4.2 *Economic growth and CO_2 emission (EKC hypothesis)*

The coefficient estimates for lnEgr and lnEgrSQ in Table 6 Panel A are both statistically significant at the 1% level and have positive and negative signs, respectively, across the four model specifications (see estimates in columns 1–4). These estimates support the validity of the EKC inverted U-shaped relationship between economic growth and territorial-based CO_2 emissions in the selected SSA countries. In other words, economic growth contributes to territorial-based CO_2 emissions at the early stages of development; however, once a threshold level of income is achieved, further expansion in economic activities has the capacity to

Table 6 Estimates from Driscoll–Kraay fixed-effects regression analysis

Variables	Panel A				Panel B			
	Territorial-based CO_2 emissions (TerCO2)				Trade-adjusted CO_2 emissions (TrdCO2)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lnEgr	1.986***	1.881***	2.271***	2.140***	− 1.134	− 1.153	− 0.768	− 0.695
	(0.204)	(0.262)	(0.219)	(0.312)	(0.783)	(0.803)	(0.767)	(0.801)
	[9.728]	[7.182]	[10.351]	[6.860]	[− 1.449]	[− 1.436]	[− 1.003]	[− 0.867]
lnEgrSQ	− 0.101***	− 0.093***	− 0.121***	− 0.112***	0.151**	0.154**	0.125*	0.120*
	(0.014)	(0.018)	(0.015)	(0.021)	(0.063)	(0.064)	(0.063)	(0.064)
	[− 7.183]	[− 5.208]	[− 8.192]	[− 5.382]	[2.374]	[2.412]	[1.989]	[1.866]
lnRemit	0.006*	0.006**	0.005*	0.006*	0.006**	0.007**	0.006*	0.005*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
	[2.032]	[2.198]	[1.963]	[1.970]	[2.142]	[2.222]	[2.056]	[1.952]
lnTrd-Total	0.182***				0.243***			
	(0.049)				(0.079)			
	[3.708]				[3.070]			
lnTrd-Export		0.106**		0.031		0.116**		− 0.018
		(0.041)		(0.049)		(0.054)		(0.067)
		[2.623]		[0.633]		[2.145]		[− 0.263]
lnTrd-Import			0.150***	0.131**			0.223***	0.233**
			(0.047)	(0.053)			(0.075)	(0.089)
			[3.215]	[2.469]			[2.963]	[2.625]
lnRen	− 1.053***	− 1.042***	− 1.048***	− 1.052***	− 0.858***	− 0.836***	− 0.856***	− 0.854***
	(0.085)	(0.079)	(0.087)	(0.088)	(0.146)	(0.144)	(0.142)	(0.143)
	[− 12.400]	[− 13.221]	[− 12.006]	[− 11.901]	[− 5.882]	[− 5.803]	[− 6.008]	[− 5.956]

Table 6 (continued)

Variables	Panel A				Panel B			
	Territorial-based CO_2 emissions (TerCO2)				Trade-adjusted CO_2 emissions (TrdCO2)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	−6.519***	−5.848***	−7.351***	−6.885***	2.254	2.740	1.163	0.900
	(0.731)	(0.927)	(0.765)	(1.169)	(2.013)	(2.243)	(1.930)	(2.163)
	[−8.920]	[−6.309]	[−9.609]	[−5.888]	[1.120]	[1.222]	[0.603]	[0.416]
Observations	391	391	391	391	391	391	391	391
Number of groups	17	17	17	17	17	17	17	17

Standard errors in (); t-statistics in []; $^{***}p<0.01$, $^{**}p<0.05$, $^{*}p<0.1$

Source: Authors' computations using STATA 16

Table 7 Distributional effects using MM-QReg approach

Variables	(1) Location	(2) Scale	(3) Qtile_5	(4) Qtile_10	(5) Qtile_25	(6) Qtile_50	(7) Qtile_75	(8) Qtile_90	(9) Qtile_95
Panel A: Territorial-based CO_2 emissions (TerCO2)									
lnEgr	2.140***	0.354	1.484**	1.600***	1.809***	2.139***	2.509***	2.684***	2.819***
	(0.480)	(0.255)	(0.678)	(0.612)	(0.528)	(0.482)	(0.559)	(0.637)	(0.723)
	[4.459]	[1.386]	[2.188]	[2.614]	[3.429]	[4.442]	[4.491]	[4.213]	[3.897]
lnEgrSQ	−0.112***	−0.021	−0.073	−0.080*	−0.092**	−0.112***	−0.134***	−0.145***	−0.153***
	(0.035)	(0.019)	(0.049)	(0.044)	(0.038)	(0.035)	(0.041)	(0.046)	(0.052)
	[−3.203]	[−1.144]	[−1.482]	[−1.790]	[−2.398]	[−3.194]	[−3.296]	[−3.124]	[−2.929]
lnRemit	0.006**	0.004***	−0.003	−0.001	0.001	0.006**	0.010***	0.013***	0.014***
	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)	(0.004)
	[2.581]	[3.845]	[−0.730]	[−0.395]	[0.602]	[2.508]	[4.051]	[4.139]	[3.625]
lnTrd-Export	0.031	−0.041	0.107	0.094	0.069	0.031	−0.011	−0.032	−0.047
	(0.053)	(0.028)	(0.075)	(0.068)	(0.059)	(0.053)	(0.062)	(0.071)	(0.081)
	[0.586]	[−1.443]	[1.416]	[1.375]	[1.184]	[0.585]	[−0.184]	[−0.447]	[−0.587]
lnTrd − Import	0.131**	0.074**	−0.006	0.018	0.062	0.131**	0.209***	0.246***	0.274***
	(0.055)	(0.029)	(0.083)	(0.073)	(0.061)	(0.056)	(0.065)	(0.075)	(0.089)
	[2.372]	[2.516]	[−0.072]	[0.251]	[1.014]	[2.346]	[3.232]	[3.283]	[3.061]
lnRen	−1.052***	0.056	−1.155***	−1.137***	−1.104***	−1.052***	−0.994***	−0.966***	−0.945***
	(0.135)	(0.072)	(0.187)	(0.170)	(0.148)	(0.135)	(0.157)	(0.178)	(0.198)
	[−7.817]	[0.780]	[−6.194]	[−6.680]	[−7.473]	[−7.808]	[−6.344]	[−5.433]	[−4.761]
Constant	−6.885***	−1.642*	−3.840	−4.377**	−5.350***	−6.883***	−8.599***	−9.413***	−10.040***
	(1.649)	(0.876)	(2.383)	(2.121)	(1.815)	(1.660)	(1.919)	(2.200)	(2.548)
	[−4.177]	[−1.874]	[−1.612]	[−2.063]	[−2.947]	[−4.147]	[−4.482]	[−4.279]	[−3.940]

Table 7 (continued)

Variables	(1) Location	(2) Scale	(3) Qtile_5	(4) Qtile_10	(5) Qtile_25	(6) Qtile_50	(7) Qtile_75	(8) Qtile_90	(9) Qtile_95
Panel B: Trade – adjusted (consumption – based) CO_2 emissions (TrdCO2)									
lnEgr	−0.695	0.773	−2.279	−1.919	−1.416	−0.555	0.041	0.422	0.676
	(0.974)	(0.588)	(2.002)	(1.618)	(1.301)	(0.939)	(0.902)	(1.009)	(1.125)
	[−0.713]	[1.315]	[−1.139]	[−1.186]	[−1.088]	[−0.591]	[0.046]	[0.419]	[0.601]
lnEgrSQ	0.120	−0.059	0.241	0.213*	0.175*	0.109	0.064	0.035	0.016
	(0.075)	(0.045)	(0.155)	(0.125)	(0.101)	(0.073)	(0.070)	(0.078)	(0.087)
	[1.592]	[−1.292]	[1.557]	[1.703]	[1.737]	[1.506]	[0.918]	[0.450]	[0.182]
lnRemit	0.005**	0.004**	−0.002	−0.000	0.002	0.006***	0.009***	0.011***	0.012***
	(0.002)	(0.001)	(0.006)	(0.004)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)
	[2.280]	[2.417]	[−0.293]	[−0.018]	[0.682]	[2.624]	[3.960]	[4.109]	[3.972]
lnTrd – Export	−0.018	−0.075*	0.136	0.101	0.052	−0.031	−0.089	−0.126*	−0.150*
	(0.065)	(0.039)	(0.146)	(0.110)	(0.088)	(0.063)	(0.061)	(0.069)	(0.078)
	[−0.270]	[−1.897]	[0.930]	[0.915]	[0.596]	[−0.493]	[−1.466]	[−1.829]	[−1.933]
lnTrd – Import	0.233***	0.032	0.169	0.183	0.204**	0.239***	0.263***	0.279***	0.289***
	(0.070)	(0.042)	(0.135)	(0.115)	(0.093)	(0.067)	(0.065)	(0.072)	(0.079)
	[3.341]	[0.749]	[1.244]	[1.592]	[2.188]	[3.560]	[4.064]	[3.884]	[3.642]
lnRen	−0.854***	−0.036	−0.780**	−0.797***	−0.820***	−0.860***	−0.888***	−0.905***	−0.917***
	(0.185)	(0.112)	(0.350)	(0.304)	(0.247)	(0.178)	(0.172)	(0.190)	(0.209)
	[−4.611]	[−0.320]	[−2.227]	[−2.621]	[−3.323]	[−4.835]	[−5.168]	[−4.772]	[−4.387]
Constant	0.900	−2.057	5.117	4.158	2.820	0.529	−1.058	−2.073	−2.747
	(2.902)	(1.751)	(5.866)	(4.809)	(3.874)	(2.795)	(2.689)	(2.998)	(3.336)
	[0.310]	[−1.175]	[0.872]	[0.865]	[0.728]	[0.189]	[−0.394]	[−0.691]	[−0.823]
Observations	391	391	391	391	391	391	391	391	391

Standard errors in (); t-statistics in []; $^{***}p<0.01$, $^{**}p<0.05$, $^{*}p<0.1$. Source: Authors' Computations using STATA 16 induce a shift away from pollution-intensive technologies and toward a cleaner and more environmentally friendly production pattern. Furthermore, the validation of the EKC suggests that the SSA region is still at the scale stage where emphasis is more on the economic growth path relative to environmental sustainability. These results are consistent with the findings of Pandey et al. (2020) for territorial-based CO_2 emissions in the Asian economies. Estimates in Panel B of Table 6 explain trade-adjusted CO_2 emissions (TrdCO2). In contrast, the estimates show that lnEgr has a statistically insignificant negative coefficient. For lnEgrSQ, the coefficient is positive and statistically significant in all the model specifications. These estimates suggest that the EKC hypothesis is not valid in explaining trade-adjusted CO_2 emissions in the selected SSA countries. Interestingly, Pandey et al. (2020) also observed similar conditions for the Asian economies. These findings are suggestive for policymakers in the SSA bloc to tighten their commitment to environmental strategies and regulation via channels of green growth, i.e., efforts to decouple economic growth from emission levels should be pursued, while on the part of society, the need for environmental awareness should be advanced through research and development (R&D) and the adoption of new technologies that promote growth without compromise to environmental quality (Balsalobre-Lorente et al. 2018).

Estimates in Panel A of Table 7 show a valid EKC relationship for all sections of the quantile distribution of territorial-based CO_2 emissions. Both lnEgr and lnEgrSQ show that economic growth has stronger impact on territorial-based CO_2 emissions in countries at the upper quantiles. This is similar to what Akram et al. (2020) reported for developing economies but a reverse of the findings of Zhang et al. (2016), which showed a stronger inverted U-shaped curve at the lower quantiles of carbon emissions distribution in APEC countries. The coefficient of lnEgr in Panel B is statistically insignificant across all the quantiles (confirming the results in Panel B of Table 6). For the square term, lnEgrSQ, the coefficient is positive but statistical significance is achieved at the 10% level only for counties at the lower quantiles. Clearly, the estimates in Panel B suggest that the EKC hypothesis is not valid in explaining trade-adjusted CO_2 emissions in the selected SSA countries. Taking a comparative look at the coefficient of lnEgrSQ in Panel A (TerCO2) and in Panel B (TrdCO2) across the quantiles, it is evident that further expansion in economic growth will reduce territorial-based CO_2 emissions. On the other hand, it will also increase CO_2 embedded in the consumption pattern in countries below the median quantile. This condition highlights the special case of net importing economies. With a low level of production capacity and a high dependence on trade to fill gaps in domestic demand, SSA countries are exposed to CO_2 emissions embedded in goods produced in other economies. Without a mitigation strategy, the quest for higher levels of economic growth would result in increased consumption and, consequently, increased environmental burden transfer in the form of CO_2 emissions.

4.3 *Remittances and CO_2 emissions*

International remittance inflows have a positive impact on CO_2 emissions through domestic production and trade-induced consumption activities, as shown by the positive and statistically significant coefficient of lnRemit in Panel A (TerCO2) and in Panel B (TrdCO2). However, when compared to the impact of the other variables in the model, the contribution is the smallest. The coefficient across the specifications in Panel A and Panel B suggests that the impact does not vary much, as a unit increase in international remittance inflows contributes to CO_2 emissions in the selected SSA countries by 0.005–0.007%, regardless of whether emissions are adjusted for trade or not. In general, the environmental impact of international remittance inflows in these SSA countries supports the evidence from Sri Lanka, Pakistan, and Bangladesh (Rahman et al. 2019) and the Philippines (Karasoy 2021) but differs significantly from the condition reported for India and a panel of Asian countries by Khan et al. (2020a) and Wang et al. (2021), respectively. In comparison to the case of net exporters of CO_2, for example, India (see Khan et al. 2020a), estimates in Table 6 show that the conditions in net carbon importing economies may differ significantly. This could be a significant factor in determining how international remittances are used in developing countries.

Table 7 shows that in the lower quantiles, international remittance inflows (lnRemit) have a negative but statistically insignificant impact on territorial-based CO_2 emissions, but in the middle and upper quantiles, they have a positive and statistically significant coefficient. The results demonstrate that countries in the upper quantiles have a greater environmental impact, with a unit increase in foreign remittance inflows producing a 0.006% rise in territorial-based CO_2 emissions in the median quantile and 0.014% in the 95th quantile. The coefficient of lnRemit in Panel B follows a similar pattern, with statistical significance achieved only for countries in the median and upper quantiles, and a unit increase in international remittance inflows contributing to a 0.006% increase in trade-adjusted CO_2 emissions in the median quantile and 0.012% in the 95th quantile. Usman and Jahanger (2021) found in a global sample of 93 countries that remittances induce more CO_2 emissions in countries at the lower quantiles. Using disaggregated CO_2 emission data, our findings in Table 7 show that remittances, in the case of net importing economies, induce more CO_2 emissions in countries at the upper quantiles. These findings, as suggested by Brown et al. (2020), Elbatanony et al. (2021) and Jiang et al. (2021), imply that an increase in international remittance inflows translates into increased demand for imported household and industrial goods, such as new vehicles, electrical appliances, and mining equipment, and thus higher CO_2 emissions.

4.4 *Trade liberalization and CO_2 emissions*

From Table 6, turning to the environmental impact of trade liberalization, the coefficient of lnTrd-Total is positive and statistically significant for both territorial-based (see estimates in column 1) and consumption-based (see estimates in column 5) CO_2

emissions. These estimates suggest that the net environmental effect of trade liberalization is positive on CO_2 emissions and has a larger impact when policy choices seek to fill the gap between domestic production and consumption demands through trade. By implication, trade liberalization policies in the SSA economies do not mitigate associated environmental concerns, such as embodied CO_2 emissions in traded goods. This result, as resonated in the study of Shahbaz et al. (2017), is indicative that liberalization of trade contributes to the growing environmental deterioration concerns. From a policy standpoint, the SSA bloc must be cautious in terms of trade influx from other blocs, particularly those from regions with weak carbon mitigation policy frameworks. Worthy of mention is the recent free trade agreement among African economies, the African Continental Free Trade Area (AfCFTA), which aims at promoting economic integration and associated economic benefits. The AfCFTA policy, if not well-structured, may well expose SSA economies to environmental concerns arising from trade flows from the North African region.

This finding adds to the expanding body of empirical evidence that trade liberalization has a *pollution-haven* effect in the Sub-Saharan African economies (see, e.g., Sannassee and Seetanah 2016 for Mauritius; Solarin et al. 2017 for Ghana; and Vural 2020 for a panel of eight Sub-Saharan African economies). Thus, taking into consideration the environmental aspects of the inflows of multinational corporations, especially those from developed economies who are looking for available markets for their products that could not meet stringent environmental standards in their home country, would form a key ingredient in the restructuring of trade liberation policies in the region. Dirty operations of multinationals could be contributing to harmful environmental consequences in the form of CO_2 emissions. The plausible reason is that institutional and environmental policy frameworks are still very weak in the developing SSA region. From a policy standpoint, there is a need for strong institutions that will place the long-term welfare of the people above short-term benefits by applying stringent regulations on the environmental aspects of the trade and other economic activities of multinationals. In contrast to the theoretically expected role of exports in driving domestic production (Khan et al. 2020b), estimates in column 4 show that import trade, with a statistically significant coefficient of 0.131%, accounts for the majority of the impact of trade liberalization on the growth of CO_2 emissions from domestic production activities in the selected SSA economies. This is also different from the condition in OECD and non-OECD countries, as reported by Liddle (2018). The coefficient of lnTrd-Import in column 8 indicates that import trade has a positive effect on consumption-based CO_2 emissions, with a coefficient of 0.233%, which is statistically significant at the 5% level. As expected, the contribution of imports to CO_2 emissions is larger through the consumption demands of these selected SSA economies.

The estimates in Panel A of Table 7 show a statistically insignificant coefficient for lnTrd-Export across all quantiles and a positive coefficient for lnTrd-Import with statistical significance at the 5% level for countries at the median quantile and at the 1% level for countries at the upper quantiles. Looking at the size of the coefficient of lnTrd-Import across the quantile distributions, it is clear that the 0.274% impact of a unit increase in import trade on territorial-based CO_2 emissions in countries at the upper quantiles represents the strongest. Estimates in Panel B, however, show that lnTrd-Export has a negative coefficient with statistical significance achieved at the

10% level only at the upper quantiles. The coefficient of lnTrd-Import, on the other hand, is positive as expected; however, it is only statistically significant at the 5% level for 25th quantile and at the 1% for the median and upper quantiles. The size of the coefficients shows that import trade also has a stronger environmental impact in countries at the upper quantiles.

Existing climate legislation and international agreements are based on territorial-based emissions (Andrew et al. 2013). However, our empirical evidence shows that the primary cause of rising CO_2 emissions in SSA economies is the importation of goods from other economies. Low technological development, like in other developing economies, is a major factor in SSA countries' overreliance on imported consumer and manufactured goods, as well as capital equipment (Nyankakyi and Munemo 2017). From this perspective, a number of recent studies have called for increased access to renewable energy as an urgent step toward ensuring the sustainability of development targets in emerging economies (Hu et al. 2020; Hasanov et al. 2021).

4.5 *Renewable energy use and CO_2 emissions*

The role of renewable energy in helping SSA economies respond to trade-induced environmental concerns is explained by the sign and size of the coefficient of lnRen in Table 6. The coefficient estimates are statistically negative and significant at the 1% level. Based on the size of the coefficients, a unit increase in the share of renewable energy in the total energy mix reduces territorial-based CO_2 emissions by 1.042–1.053%. For trade-adjusted CO_2 emissions, a 0.836–0.858% mitigation effect is achieved by altering the energy mix with a unit increase in renewable energy. These estimates suggest that investment in renewable energy will be crucial to the mitigation of environmental-related sustainability concerns in the SSA region. To this end, there is a need for a paradigm shift in the current energy mix to renewable energy, both in the area of domestic production and in bridging the energy demand–supply gap in the region. Clearly, the role of SDG target 7.2 in achieving the climate action goal defined in SDG 13 is highlighted in this component of the findings of this study. Net importing economies, in particular, can rely on renewable energy to design cleaner and more sustainable consumption and production patterns. For Hasanov et al. (2021), Zafar et al. (2020), Adedoyin et al. (2021), and Destek and Aslan (2020) all reported similar empirical evidence for the BRICS, OECD, West African, and G7 countries, respectively.

For all quantile distributions of TerCO2 and TrdCO2 in Table 7, the coefficient of lnRen is negative and statistically significant at the 1% level. The estimates in Panel A show that a unit increase in renewable energy use reduces territorial-based CO_2 emissions in all the quantiles, but the mitigation effect is greater in the lower quantiles; 1.155% mitigation effect at the 5th quantile and 0.945% at the 95th quantile. This is similar to the condition described by Akram et al. (2020) for a group of 66 developing countries. The mitigation effect of a unit increase in renewable energy consumption on trade-adjusted CO_2 emissions is, however, greater in the upper quantiles based on the estimates in Panel B, with a 0.780% mitigation effect in the 5th quantile and a 0.917% mitigation effect in the 95th quantile. Developing an environmental policy framework for sustainable development in net importing economies would therefore require substituting renewable energy sources for fossil fuels (Hu et al. 2020). This will ensure that the economic benefits of international remittances and trade liberalization policies are realized in less carbon-intensive ways.

5 Conclusions and policy discussion

In this study, we examined the impacts of international remittance inflows, trade liberalization, and renewable energy consumption on territorial-based and trade-adjusted CO_2 emissions in a panel of 17 net carbon-importing Sub-Saharan African countries during the period 1995–2017. We used a quantile-based approach that takes into account the SDG components for environmental sustainability. The empirical findings show that, first, the EKC hypothesis does not explain trade-adjusted CO_2 emissions in the selected countries. However, for all quantiles of the distribution, there exists an inverted U-shaped EKC relationship between economic growth and territorial-based CO_2 emissions, with a stronger impact in countries in the upper quantiles. Second, international remittance inflows have a statistically significant positive impact on both territorial-based and trade-adjusted CO_2 emissions in the middle and upper quantiles of the distribution, but are statistically insignificant in the lower quantiles. Third, trade liberalization, on the one hand, has a statistically insignificant impact on CO_2 emissions through exports. Imports, on the other hand, have a positive impact on both territorial-based and trade-adjusted CO_2 emissions. The impact, however, is not statistically significant in lower quantile countries, but is larger and statistically significant in middle and upper quantile countries. Lastly, renewable energy use has a negative and statistically significant impact on both territorial-based and trade-adjusted CO_2 emissions in all the quantiles, but the mitigation effect is greater in the upper quantiles of the trade-adjusted CO_2 emissions. On the basis of these empirical results, we draw the following important conclusions:

- Remittances increase the territorial-based and trade-adjusted CO_2 emissions in net-importing Sub-Saharan African economies, putting a strain on the environment.
- Trade liberalization increases CO_2 emissions in the economies via imports and has a greater environmental impact through consumption-induced CO_2 emissions.
- Net-importing developing economies can use renewable energy to address environmental challenges posed by trade policy decisions and economic integration.

Considering that the study was conducted for a good number of net carbon-importing Sub-Saharan African countries, the following related policy dimensions are inferred for the region and other similar economies: In spite of the adverse environmental consequences, the dependency of most SSA economies on international remittance inflows suggests that enacting a law that prohibits international remittances could be a disservice to these economies. Rather, citizens should be more informed through deliberate awareness about sustainable and/or green business and investment opportunities. The conversion of these remittances to the aforementioned opportunities has the potential to mitigate the carbon emission-related effects that arise from the usual economic but less environmentally beneficial consumption. Additionally, this study offers policy inferences for the newly promulgated African Continental Free Trade Area (AfCFTA). As the AfCFTA policy is largely trade-related, and trade implications have been inferred from this investigation, the AfCFTA policy is expected to accommodate the protection of endangered animal and plant species, the ecosystem, and stricter restrictions on the discharge of environmentally hazardous industrial products, chemicals, and others. While the AfCFTA's economic benefits are widely anticipated, much can be learned from the world's largest trading bloc—the European Union's Green Deal for commerce and the environment. In addition, renewable energy offers SSA countries the opportunity to reduce their dependence on coal and fossil fuel-based energy sources. Harnessing the region's vast renewable energy potential will represent a significant opportunity to meet economic development goals and ensure that the economic benefits of remittance inflows and trade liberalization policies are delivered in a less carbon-intensive manner. For example, partnerships with energy multinationals and the private and public sectors could expand the development of renewable energy sources to better ensure economic opportunity and environmental sustainability, in addition to meeting the continent's growing energy needs.

This study focused on SSA countries where consumption-based CO_2 emissions are equal or higher than territorial CO_2 emissions (i.e., countries that are net importers of CO_2 emissions and countries with zero net transfer of CO_2 emissions), removing the net exporters in the region, Nigeria and South Africa, from the panel constructed for the analysis. A similar study can be performed for net-carbon importing countries in other developing regions. Future studies may consider providing comparative evidence by studying the specific case of net-carbon exporting economies. Such comparative studies may as well consider comparing developing countries to developed countries when country selection is defined by trade dependence. These research gaps can further environmental policy discourse.

Funding This study was not funded by any organization.

Data availability Data used in the study were collected from databases that grant open access and are provided in Table 1.

Software STATA 16.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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