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Have international remittance inflows degraded environmental quality? A carbon emission mitigation analysis for Ghana

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Abstract
Despite the considerable contributions of remittances to households and economic advancements, their environmental implications have received little attention in empirical research. This study was, therefore, conducted to help fill that gap, using Ghana as an evidence. In achieving the above goal, robust econometric methods that control for endogeneity, heteroscedasticity and serial correlation among others, were engaged for the analysis. From the results, the studied variables were first-differenced stationary and cointegrated in the long run. The elasticities of the predictors were explored via the FMOLS, DOLS and CCR estimators, and from the results, remittance inflows worsened the ecological quality in Ghana through high CO_2 emissions. Also, population growth and energy utilization were not friendly to the country's environment; however, technological innovations improved environmental quality in the nation via low CO_2 effusions. The VECM was employed to examine the path of causalities amidst the series, and from the results, there were bidirectional causalities between remittance inflows and CO_2 emissions and between population growth and CO_2 emanations. Also, a causation from energy utilization to CO_2 effluents was discovered; however, there was no causality between technological innovations and CO_2 exudates in the country. Based on the findings, it was recommended among others that, authorities should enact regulations to control the activities of polluting industries that are being financed by remittances. Also, households and individuals should minimize their use of remittances to finance carbon-intensive items, like automobiles and air-conditioners among others, that add to environmental pollution in the country.

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Introduction

The international community is currently facing a serious problem in the form of environmental pollution (Musah et al. 2020a; Zhao et al. 2022). Carbon dioxide (CO_2) emissions, which represent a large portion of greenhouse gas (GHG) effusions, have been identified as a key agent of ecological pollution (Rej et al. 2022; Musah et al. 2020b; Murshed 2022). According to the International Energy Agency (IEA), global emissions in the year 2020 rose by 2% or 60 million tonnes, as compared to the same month the previous year (Musah et al. 2020c). To the body, recovery of the major economies after the COVID 19 pandemic is responsible for this rise, since the execution of economic activities in various economies is heavily reliant on carbon-intensive energies that result in high pollution. The lack of significant policy measures to help promote green activities in various jurisdictions could also be a factor for the surge in global emissions (Söderholm 2020; Levin et al. 2019). Due to the galloping rate of emissions and its adverse consequences on the environment, numerous investigations on the determinants of environmental quality (EQ) have been conducted in different settings. For example, Murshed et al. (2022), Ma et al. (2021), Rehman et al. (2021), Liu et al. (2021), Murshed et al. (2021a) and Rej et al. (2021) confirmed energy utilization as a material determinant of EQ, while Yao et al. (2021), Zeraibi (2021), Ahmed et al. (2021) and Ibrahim and Vo (2021), affirmed financial development as a significant determinant of CO_2 emanations.

Of late, explorations on remittances and environmental quality (EQ) are also gaining popularity due to the rising levels of remittances in various economies. According to the World Bank, global remittances increased by 10% to US$689 billion in 2018 with US$528 billion going to developing nations. The body also predicted overall global remittances to rise by 7% US$715 billion, with US$549 billion going to developing countries. The rise in remittances has two main implications on the environment. According to Khan et al. (2020), Qingquan et al. (2020), Yang et al. (2021b) and Jamil et al. (2021), if remittance inflows (RI) are used to finance high-polluting industries and carbon-intensive items like automobiles and air conditioners among authors, then remittances would have a detrimental effect on EQ, due to high CO_2 effusions. Contrastingly, if the influxes of remittances are used to finance green energy and ecologically harmless technologies, then, remittances would have a beneficial influence on EQ via low CO_2 secretions (Usama et al. 2020; Zafar et al. 2021; Wang et al. 2021).

In the SDGs of the United Nations, remittances support the attainment of 15 of the goals. For instance, by improving the living standards of households, remittances help to attain SDG 1.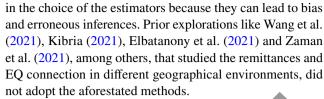 Also, SDG 2 will be achieved if remittances are used to reduce hunger, promote lasting agriculture, improve nutrition and ensure food security. Moreover, SDG 3 will be attained if remittances are used to promote healthy lives and the well-being of individuals of all ages. Furthermore, remittances facilitate the attainment of SDG 4 if they are used to boost lifelong learning opportunities and promote inclusive and equitable quality education. Also, if remittances are used to empower women and girls and promote gender equality in our society, the motive of SDG 5 will be accomplished. Additionally, SDG 6 will be attained if remittances are used to support sustainable water and sanitation in various economies. Moreover, if remittances are used to promote access to modern and sustainable energy, then SDG 7 will be achieved. Furthermore, SDG 8 will be accomplished if remittances are used to support investments in activities that promote sustainable economic growth. Also, if remittances are used to back sustainable industrialization and eco-friendly innovations, then SDG 9 will be attained. Moreover, the aim of SDG 10 will be met if remittances help to eliminate intra-and inter-country inequalities. Additionally, SDG 11 will be attained if remittances are used to finance activities that promote sustainable cities and societies. Besides, if remittances are used to fund activities that support sustainable production and consumption patterns, then SDG 12 will be accomplished. Also, SDG 13 will be attained if remittances are used to support activities that minimize climate change and its adversities. Furthermore, the target of SDG 14 will be met if remittances are used to protect and sustainably utilize oceans, seas and marine resources for long-lasting development. Moreover, SDG 15 will be attained if remittances are used to fund initiatives that help to battle desertification, maintain forests and terrestrial ecosystems and prevent land pollution. Finally, if remittances are used to support peaceful and inclusive societies for long-term development, SDG 16 will be accomplished.

Though remittances are key drivers of the majority of the SDGs, numerous explorations have identified them as a potential source of environmental degradation. For example, Usman and Jahanger's (2021) study on 93 countries, Yang et al.'s (2021b) research on 97 nations, Khan et al.'s (2020) analysis on BRICS economies, Jamil et al.'s (2021) exploration on G-20 economies, Qingquan et al.'s (2020) research on Australia, Yang et al.'s (2021a) study on BICS economies, Neog and Yadava (2020) investigation on India and Kibria (2021) study on Bangladesh among others, all confirmed remittances as harmful to EQ. Despite the countless explorations on remittances and EQ, there has been no study on the linkage amidst the series in Ghana after a thorough review of the literature. Thus, available literature regrettably offers minimal insights on the nexus between remittances and EQ in Ghana. However, considering the nation's pivotal position in combating global GHG emissions (which have been predicted to increase by another 50% by 2050

relative to 2010 (OECD, 2012)), environmental threats that the country faces with respect to the influxes of remittances warrant further scrutiny. This motivated the conduct of the study. Ghana is a very dynamic nation in Africa and has many nationals abroad who send money and other items to their relatives periodically. The remittances received by the households may be channelled to high-polluting items that could weaken ecological quality in the country. In other words, more remittances mean more aggregate consumption in the economy which ultimately puts pressure on energy demands and therefore, more CO_2 effusions. Ghana is one of the highest emitters of CO_2 in Africa. According to the World Bank, Ghana's CO_2 emissions grew 35.7% from 0.221 metric tons in 1960 to 0.30 metric tons in 1970. Also, the nation's CO_2 emanations were 0.232 metric tons in 1980, representing a 4.9% rise from the 1960 figure. Similarly, the CO_2 effluents of Ghana surged by 34.8% between 1960 and 2000 and by 103.6% between 1960 and 2010. Finally, CO_2 exudates of the country rose by 144.8% from 1960 to 2018. Looking at the above statistics, we assumed that remittances could be among the factors responsible for the surging rate of emissions in the country. Therefore, studying the linkage between remittances and EQ to help raise policy options to improve EQ in the country and to help reduce global GHG effusions to net-zero by 2050, was deemed essential.

Our exploration revolves around these questions: (1) What is the effect of remittances on EQ in Ghana? (2) What causal relationship exists between remittances and EQ in Ghana? Answers to these questions would help raise vital policy options that could promote the nation's EQ. The contributions of this study are three folds. First, after a thorough review of literature, this study is a groundbreaking study that investigated the connection amidst remittance inflows and Ghana's EQ. Prior explorations like Lin and Agyemang (2019), Kwakwa (2019), Abokyi et al. (2021), Asumadu-Sarkodie and Owusu (2016), Kingsley et al. (2017) and Yakubu et al. (2021) are limited since they centred on the linkage between other macroeconomic variables and Ghana's EQ, but not between remittances and EQ of the country. Secondly, most prior studies on the connection amidst remittances and EQ only estimated the elasticities of the predictors without touching on the causalities amidst the series (for example, Neog and Yadava 2020; Zafar et al. 2021; Usman and Jahanger 2021 and Yang et al. 2020). However, to Li et al. (2020a, 2020b) and Musah et al. (2021b, 2021c), if variables are flanked by a long-term relationship, it does not guarantee that the series cause each other. The Engle and Granger (1987) VECM causality test were, therefore, adopted to explore the causations between the variables. Finally, the study applied advanced time series econometric methods (thus the FMOLS, DOLS and CCR estimators), that control for endogeneity, heteroscedasticity and serial correlation in its analysis. The above issues were considered

in the choice of the estimators because they can lead to bias and erroneous inferences. Prior explorations like Wang et al. (2021), Kibria (2021), Elbatanony et al. (2021) and Zaman et al. (2021), among others, that studied the remittances and EQ connection in different geographical environments, did not adopt the aforestated methods.

In examining the nexus amidst remittances and EQ, a well-outlined econometric process was followed. Firstly, stationarity tests were conducted to examine the integration features of the series. Afterward, a test to examine the variables' cointegration properties was undertaken. At the third stage, the elasticities of the predictors were estimated, whilst the path of causality amidst the series was explored at the final stage. Our exploration is unique since it was written from our own point of view. In comparison to previous studies on Ghana, this study is novel because it uncovers fresh information. The study is finally innovative since the processes engaged are thoroughly detailed, and the results are accurately presented and discussed. This study was organized into five sections. "Introduction" presents the study's introduction, while "Literature review" centres on the review of the literature. "Materials and methods" is on the materials and methods adopted for the study, while "Results and discussions" presents the study's results and discussions. The conclusions, policy recommendations and study limitations are displayed in "Conclusions and policy recommendations".

Literature review

Remittances are monies or goods sent by migrants or foreign workers to their home countries to supplement household income (Vargas-Silva 2018; Grigoryan and Khachatryan 2018; Al-Assaf and Al-Malki 2014). The International Monetary Fund (IMF), which is the main provider of international remittance statistics based on Central Bank data, also defined remittances as the sum of personal transfers and compensation of employees. According to Levitt (1998), the behaviours, ideas, identities and expertise that migrants gain while living in other countries and can be sent back to their home countries also form part of the remittances. As reported by the IMF, low-income countries rely heavily on remittances, which account for over 4% of their GDP, as compared to roughly 1.5% of that of middle-income countries. Because the statistical criteria used to gather data on remittances are broader, global estimates of migrant transfers may include transactions that are not remittances. Also, it is difficult to estimate the exact size of remittances, because many remittances are sent through unofficial means (IMF, 2009). It should be noted, therefore, that the World Bank and the IMF estimates are based on remittances sent via official channels like banks. Not all migrant transactions through

transfer operators (like Western Union), mobile money transfers and post offices are included in the remittances of countries, neither are informal transfers like those made through friends, relatives, or transport entities returning to home countries. According to Irving et al. (2010) and World Bank (2011), the above unofficial transfers understate the remittances of nations by 50%. Due to that, some countries particularly in Sub-Saharan Africa, fail to disclose remittance figures in their balance of payments. As reported by Plaza and Ratha (2017), Irving et al. (2010) and the World Bank (2011), data on remittances may vary across nations due to variations in legislative and policy frameworks, simplification of data processes and differences in data availability.

The linkage between other macroeconomic factors and EQ have been expansively explored (for instance, Yang et al. 2021a, b; Jahanger et al. 2022; Usman and Makhdum 2021; Usman and Balsalobre-Lorente 2022; Huang et al. 2022; Usman et al. 2022a; Usman et al. 2022b and Usman et al. 2021a, b, among others); however, the connection between remittances and EQ has received minimal attention. On the examples of such studies, Usman and Jahanger (2021) conducted a study on 93 countries from 1990 to 2016. The study employed the panel quantile regression technique for the analysis. From the estimates, RI degraded EQ in the 5th to 70th quantiles but improved EQ in the 80th to 95th quantiles. Yang et al. (2021a, b) studied BICS countries over the period 1990 to 2016. The study's results found RI as harmful to the nations' EQ. Rahman et al. (2019) explored the linkage between remittances and EQ in some selected Asian countries from 1982 to 2014 and discovered that remittances spurred ecological pollution in the nations. Yang et al. (2020) explored the linkage between RI and EQ in 97 countries over the period 1990 to 2016. The GMM estimates of the study confirmed RI as a driver of ecological pollution in the nations. Zafar et al. (2021) researched on top 22 remittance-receiving countries from 1986 to 2017 and disclosed RI as friendly to EQ. Wang et al. (2021) studied five-remittance receiving nations from 1980 to 2016. The study's findings confirmed RI as friendly to the countries' EQ. Neog and Yadava (2020) conducted a study on India from 1980 to 2014 and discovered that positive shocks in remittances harmed EQ in the nation; however, negative shocks in remittances improve the country's ecological quality. Azam et al. (2021) studied 30 developing economies over the period 1990 to 2017. The study employed the PVAR technique in its analysis, and from the results, remittances had a detrimental influence on the nations' EQ. Khan et al. (2020) investigated BRICS countries over the period 1986 to 2016. The FM-LS and the CCEMG estimates of the study affirmed RI as an agent of pollution in the nations. Ahmad et al. (2019) researched on China and disclosed that positive shocks in remittances deteriorated EQ in the

nation; however, negative shocks in remittances improved the country's ecological quality.

Jamil et al. (2021) analysed G-20 countries from 1990 to 2019 and disclosed that RI weakened EQ in the nations. In Bangladesh, Kibria (2021) examined the connection between RI and EQ over the period 1980 to 2016. From the NARDL estimates of the study, positive shocks in RI promoted ecological pollution in the country, however, negative shocks in RI were friendly to the nation's EQ. Elbatanony et al. (2021) assessed the environmental impacts of remittances on developing economies from 1980 to 2014. From the results, an N-shape between remittances and pollution was discovered for lower-middle-income countries, whilst a U-shaped curve was disclosed for upper-middle-income countries from the 40th to the 80th quantiles. For the period 1991 to 2019, Deng et al. (2021) studied the dynamic association amidst financial inflows and EQ in BRICS economies. The NARDL-PMG technique was adopted for the analysis, and from the estimates, positive shocks in remittances had a trivial effect on EQ; however, negative shocks in remittances worsened ecological quality in the economies. Li et al. (2021a, b) investigated China from 1981 to 2019 and discovered that negative shocks in remittances promoted the country's EQ. Sharma et al. (2019) researched on Nepal and identified remittances as harmless to the nation's EQ. Zaman et al. (2021) investigated nine remittance-receiving nations from 1990 to 2014 and confirmed that remittances promoted economic progress, which is a vital agent of environmental pollution. Khan et al. (2021) researched in the context of the USA and disclosed that remittances waned EQ in the nation. Zhang et al. (2021) assessed the role of remittances in the environment of top remittance-receiving nations from 1990 to 2018. The CUP-FM and the CUP-BC estimators were employed for the analysis, and from the results, remittances had negative implications on the environment of the nations.

Brown et al. (2020) studied Jamaica from 1976 to 2014. From the revelations, a long-run cointegration association from remittances to CO_2 effusions was disclosed. Also, an asymmetric response of CO_2 exudates to variations in remittances was discovered in the short run. Villanthenkodath and Mahalik (2020) analysed the linkage between RI and EQ in India over the period 1980 to 2018. Based on the ARDL estimates of the exploration, an inverted U-shaped association amidst RI and CO_2 secretions was uncovered. Jafri et al. (2021) investigated China from 1981 to 2019. The NARDL technique was employed to estimate the coefficients of the predictors. From the results, negative shocks in remittances had a positive influence on CO_2 exudates in the country. Wawrzyniak and Doryń (2020) conducted a study on 93 emerging and developing economies for the period 1995 to 2014. From the GMM

estimates of the exploration, remittances had a trial effect on EQ. Qingquan et al. (2020) researched on Australia and disclosed that remittances undermined the nation's ecological quality. In Ethiopia, Usama et al. (2020) studied the connection amidst remittances and EQ and reported that the association between remittances and EQ was negative because most remittance-receiving families in the country shifted to clean electricity consumption. According to Thapa and Acharya (2017), remittances improve the living conditions of households, propelling them to go in for high-energy consuming items, resulting in more CO_2 effusions. Also, when the implementation of investments related to remittances results in high energy demand, the level of CO_2 effluents could escalate (Elbatanony et al. 2021). Contrastingly, Elbatanony et al. (2021) averred that, if the influxes of remittances are spent on clean energy and ecologically-harmless technologies, the effect of remittances on the effusion of carbon could be negative. Islam (2021a, 2021b) studied the asymmetrical impact of remittances on EQ in the top eight remittance-receiving countries. The study employed the panel GLS and the PMG estimation techniques to explore the coefficients of the covariates. From the results, both positive and negative changes in remittances improved EQ in the countries. Also, a feedback causality from the positive component of remittances to CO_2 effusions and a one-way causality from the negative component of remittances to ecological pollution were discovered.

Based on the literature reviewed, it can be concluded that the nexus amidst remittances and EQ are conflicting. Whilst studies like Yang et al. (2021a), Qingquan et al. (2020), Jamil et al. (2021) and Yang et al. (2021b), confirmed remittances as detrimental to EQ, others like Usama et al. (2020), Wang et al. (2020), Zafar et al. (2021) and Sharma et al. (2019), found remittances as friendly to EQ. Elbatanony et al. (2021), on the other hand, found an N-shape between remittances and ecological pollution, whilst an inverted U-shape between remittances and environmental pollution was reported in the study of Villanthenkodath and Mahalik (2020). Irrespective of the numerous studies and their contrasting findings, there has been no study on the RI-EQ connection in Ghana to the best of our knowledge. Hence, a study on remittances and EQ nexus in the context of Ghana was deemed appropriate.

Materials and methods

Data source and summary statistics

In examining the nexus amidst RI and EQ, data for the period 1980 to 2020 was used for the analysis. All missing data were filled using the data interpolation and extrapolation approach to avoid the problems associated with the use of unbalanced data. Given this, the data used for the analysis was strongly balanced. All data employed for the study were obtained from WDI (2021). More details on the investigated variables are shown in Table 1. Table 2 displays the summary statistics on the series. From the table, RI had the greatest mean value, whilst CO_2 effusions had the least mean value. Also, RI was the most volatile in terms of SD, whilst POP was the least volatile. Moreover, RI and EC had negatively skewed distributions, whilst POP, TI and CO_2 effluents had positively skewed distributions. Also, CO_2 exudates and EC had heavy tails based on the kurtosis results, whilst RI, TI and POP had thinner tails. On the correlation between the variables, RI, POP and EC were significantly positively related to CO_2 effluents. This indicates that, as RI, POP and EC rose, CO_2 exudates also rose in the same direction and vice versa. However, the association between TI and CO_2 emanations was negative and significant, suggesting that, a surge in TI led to a fall in CO_2 effusions and vice versa. From the VIF and tolerance tests outlined in Table 3, there is no collinearity amidst the explanatory variables. For robustness purposes, the Farrar and Glauber (1976) test was also conducted. From the estimates shown in Table 3, the null hypothesis of no multi-collinearity amidst the predictors could not be rejected. Finally, all the variables have significant loadings based on the PCA results shown in Table 4. This implies that all the series were relevant in predicting EQ in Ghana.

Model specification and theoretical underpinning

Studies on the predictors of environmental quality (EQ) have been immensely explored in different geographical settings. For instance, Rjoub et al.'s (2021) analysis on Turkey; Baloch et al.'s (2021) investigation on OECD economies; Ye et al.'s (2021) exploration on Malaysia; Murshed et al.'s (2021b) investigation on South Asian Neighbors and Adebayo et al.'s

Table 1 Data description and measurement unit

Variable name	Measurement	Source
Environmental quality (CO_2 emissions)	Metric tons per capita	WDI (2021)
Remittance inflows (RI)	Personal remittances, paid (current US$)	WDI (2021)
Technological innovation (TI)	Patent applications (resident + non-resident)	WDI (2021)
Population growth (POP)	Annual percentage	WDI (2021)
Energy consumption (EC)	Kg of oil equivalent per capita	WDI (2021)

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Table 2 Descriptive statistics and correlational analysis

Descriptive statistics

Statistic	$\ln CO_2$	$\ln RI$	$\ln TI$	$\ln POP$	$\ln EC$
Mean	−1.104	12.534	1.011	0.941	4.962
Median	−1.157	15.392	1.484	0.926	5.797
Maximum	−0.572	21.685	3.951	1.114	6.012
Minimum	−1.782	15.501	2.398	0.756	5.584
Std. dev	0.426	7.449	1.446	0.102	2.082
Skewness	0.721	−0.948	0.781	0.045	−1.989
Kurtosis	3.151	2.317	1.779	1.919	4.978
Jarque–Bera	3.595	6.941	6.707	2.008	33.713
Probability	0.166	0.331	0.135	0.366	0.643

Correlational analysis

Variable	$\ln CO_2$	$\ln RI$	$\ln TI$	$\ln POP$	$\ln EC$
$\ln CO_2$	1.000				
$\ln RI$	0.546	1.000			
	(0.002)***				
$\ln TI$	−0.585	0.141	1.000		
	(0.003)***	(0.380)			
$\ln POP$	0.674	−0.295	0.371	1.000	
	(0.004)***	(0.062)*	(0.017)**		
$\ln EC$	0.675	−0.307	0.284	0.739	1.000
	(0.005)***	(0.051)*	(0.072)*	(0.004)***	

Values in parenthesis () represent probabilities while ***, * denote significance at the 1% and the 10% levels, respectively

(2021a, b) study on South Korea, among others, all examine the connection between macroeconomic factors and EQ. However, to the best of the researchers' knowledge, there have been limited explorations on the remittance inflows (RI) and EQ connections in Ghana. Hence, the conduct of this study. In attaining the above objective, the following function was proposed:

Table 3 Multi-collinearity test results

Variable	VIF and tolerance tests		Farrar and Glauber test	
	VIF	Tolerance	F-test	p-value
$\ln RI$	1.21	0.826	3.055	0.004***
$\ln TI$	1.26	0.792	5.993	0.026**
$\ln POP$	2.42	0.413	4.097	0.061*
$\ln EC$	2.25	0.444	2.877	0.003***
Mean VIF	1.79	-	-	-

VIF implies variance inflation factor while ***, **, * denote significance at the 1%, 5% and the 10% levels, respectively

Table 4 Principal component analysis

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp 1	2.067	0.924	0.517	0.517
Comp 2	1.143	0.607	0.286	0.803
Comp 3	0.536	0.282	0.134	0.937
Comp 4	0.254	-	0.064	1.000

Eigenvectors (loadings)

Variable		Comp 1		Comp 2
$\ln RI$		−0.308		0.722
$\ln TI$		0.634[p]		0.228
$\ln POP$		0.620[p]		−0.050
$\ln EC$		0.345		0.687[q]

p denotes significant loadings under component 1, while q denotes significant loadings under component 2

$$CO_{2t} = f(RI_t, TI_t, POP_t, EC_t) \qquad (1)$$

where CO_2 emissions are the explained variable representing EQ, while remittance inflows (RI) is the main explanatory variable. Technological innovation (TI), population growth (POP) and energy consumption (EC) were included in the function as control variables to help minimize the consequences of omitted variable bias. The above equation was expressed in a linear form as:

$$CO_{2t} = \alpha_0 + \beta_1 RI_t + \beta_2 TI_t + \beta_3 POP_t + \beta_4 EC_t + \mu_t \qquad (2)$$

where $\beta_1, \beta_2, \beta_3$ and β_4 are the parameters of *RI, TI, POP* and *EC* respectively, while the timeframe is epitomized by t. Also, the constant term is represented by α_0, while the error term with a mean of zero and variation of σ^2 is symbolized by μ_t. Natural logarithm was taken on both sides of Eq. (2), like those of Sun et al. (2021), Usman et al. (2021a, b), Musah et al. (2021a and Ruzi et al. (2021) to help reduce the issue of heteroscedasticity. The resulting specification therefore became:

$$lnCO_{2t} = \alpha_0 + \beta_1 lnRI_t + \beta_2 lnTI_t + \beta_3 lnPOP_t + \beta_4 lnEC_t + \mu_t \qquad (3)$$

where $\ln CO_2, \ln RI, \ln TI, \ln POP$ and $\ln EC$ are the log conversions of the input and the output variables, respectively. All other items in the above equation remain as already defined. Following Usman and Jahanger (2021) and Yang et al. (2021a, b), RI was incorporated into the function as a determinant of EQ. The parameter of RI was to be positive $\left(\beta_1 = \frac{\partial \ln CO_{2t}}{\partial \ln RI_t} > 0\right)$, if consumers used remittances to fund activities that could worsen ecological quality in the country (Khan et al. 2020; Jiang et al. 2020). Otherwise, the coefficient of the variable was to be negative $\left(\beta_1 = \frac{\partial \ln CO_{2t}}{\partial \ln RI_t} < 0\right)$, if consumers channelled remittances into environment friendly activities in the nation (Neog and

Yadava 2020; Sharma et al. 2019). Following Ahmad et al. (2020) and Chaudhry et al. (2021), TI was introduced into the analysis as a predictor of EQ. The parameter of TI was to be positive $\left(\beta_2 = \frac{\partial \ln CO_{2t}}{\partial \ln TI_t} > 0\right)$, if technology promoted activities that are high-polluting in the country (Villanthenkodath and Mahalik, 2020; Khattak et al. 2020). Otherwise, the coefficient of the variable was to be negative $\left(\beta_2 = \frac{\partial \ln CO_{2t}}{\partial \ln TI_t} < 0\right)$, if technology stimulated activities that are beneficial to the nation's EQ (Ahmed and Ozturk 2018; Aldakhil et al. 2019). Toeing the line of Ruzi et al. (2021) and Guoyan et al. (2021), POP was introduced into the model as a determinant of EQ. The parameter of POP was to be positive $\left(\beta_3 = \frac{\partial \ln CO_{2t}}{\partial \ln POP_t} > 0\right)$, if POP accelerated the development of residential and industrial facilities that are carbon-intensive (Lin et al. 2021; Xie et al. 2020). Otherwise, the coefficient of the variable was to be negative $\left(\beta_3 = \frac{\partial \ln CO_{2t}}{\partial \ln POP_t} < 0\right)$, if POP helped to improve ecologically harmless activities in the nation (Fonchamnyo Fonchamnyo et al. 2021; Rahman and Vu 2021). Following Khurshid et al. (2021) and Ahmad et al. (2021), EC was finally introduced into the framework as a predictor of EQ. The parameter of EC was to be positive $\left(\beta_4 = \frac{\partial \ln CO_{2t}}{\partial \ln EC_t} > 0\right)$, if the energy used to drive economic activities of the country were from dirty sources leading to more pollution (Ali et al 2021; Rahman and Vu 2021). Otherwise, the coefficient of the variable was to be negative $\left(\beta_4 = \frac{\partial \ln CO_{2t}}{\partial \ln EC_t} < 0\right)$, if the energy used to propel the economic activities were from green sources that could advance ecological quality in the nation (Qayyum et al. 2021; Iqbal et al. 2021).

Econometric strategy

At the first stage of the analysis, the variables' integration orders were assessed via the ERS, PP, ADF and the KPSS stationarity tests. Secondly, the Johansen cointegration test was conducted to examine the variables' cointegration properties. The rule of thumb for this test is that, if there is one or more cointegration equation(s), then, the variables are materially related in the long run (Johansen 1991). This test is advantageous because it can detect multiple cointegrating vectors. As such, it is more fitting for multivariate analysis than other approaches. According to Wassell and Saunders (2008), Johansen's test is superior, in that, it treats every test variable as an endogenous variable. This test is made up of the maximum Eigenvalue test and the trace test. The hypothesis of the trace test is stated as:

$$H_0 : K = K_0 \tag{4}$$

$$H_0 : K > K_0 \tag{5}$$

where K_0 is set to zero to examine if the null hypothesis will not be validated, and if not validated, then, cointegration exists amidst the series. The maximum eigenvalue test hypothesis on the other hand is stated as:

$$H_0 : K = K_0 \tag{6}$$

$$H_0 : K > K_0 + 1 \tag{7}$$

Afterward, following Zhao et al. (2022), the FMOLS, DOLS and CCR estimators of Phillips and Moon (1999), Stock and Watson (1993) and Park (1992) respectively, were employed to estimate the elasticities of the covariates. The FMOLS and DOLS techniques are advantageous because they control for heteroscedasticity (Kiefer and Vogelsang 2005) and endogeneity (Funk and Strauss 2000) in regression analysis. According to Sulaiman and Abdul-Rahim (2018), the FMOLS and DOLS estimators help to solve the problem of serial correlation and small sample bias linked to the OLS approach. To Sulaiman and Abdul-Rahim (2017), if variables are flanked by a mixed order of integration, the estimators can still be used. In line with Pedroni (2001), the following FMOLS model was specified for estimation:

$$\begin{aligned} lnCO_{2t} = \alpha_0 &+ \beta_1 RI_t + \sum_{k=-K_i}^{K_i} \gamma_{ik} \Delta RI_{t-k} + \beta_2 TI_t + \sum_{k=-K_i}^{K_i} \gamma_{ik} \Delta TI_{t-k} \\ &+ \beta_3 POP_t + \sum_{k=-K_i}^{K_i} \gamma_{ik} \Delta POP_{t-k} + \beta_4 EC_t + \sum_{k=-K_i}^{K_i} \gamma_{ik} \Delta EC_{t-k} + \mu_t \end{aligned} \tag{8}$$

where $lnCO_{2t}$, RI_t, TI_t, POP_t and EC_t are cointegrated with slope parameters β_1, β_2, β_3 and β_4. Following Kao and Chiang (2001), the estimated DOLS model of the study was specified as:

$$\begin{aligned} lnCO_{2t} = \alpha_0 &+ \beta_1 RI_t + \beta_2 TI_t + \beta_3 POP_t + \beta_4 EC_t + \sum_{i=-1}^{i=1} \psi_i \Delta RI_t \\ &+ \sum_{i=-m}^{i=m} \beta_i TI_t + \sum_{i=-n}^{i=n} \varphi_i \Delta POP_t + \sum_{i=-o}^{i=o} \phi_i \Delta EC_t + \mu_t \end{aligned} \tag{9}$$

where i, m, n and o are the leads and lags to control for endogeneity and serial correlation. To Montalvo (1995), the CCR estimator of Park (1992) is better than other econometric techniques, like the FMOLS and the OLS because it exhibits less bias. However, if the long-run variance is not consistently estimated due to non-stationarity in errors inherited from misspecified orders, the CCR approach could be problematic (Nam 2021). Because regression does not comment on the causal connections amidst series (Qin et al. 2021), the VECM of Engle and Granger (1987), which offers consistent and reliable outcomes in time series analysis, was

finally adopted to explore the causal directions amidst the series. In attaining this aim, the ensuing error correction models were specified:

$$\Delta lnCO_{2t} = \omega_1 + \sum_{j=1}^{q} \varphi_{1,1j}\Delta lnCO_{2t-j} + \sum_{j=1}^{q} \varphi_{1,2j}\Delta lnRI_{t-j} + \sum_{j=1}^{q} \varphi_{1,3j}\Delta lnTI_{t-j}$$
$$+ \sum_{j=1}^{q} \varphi_{1,4j}\Delta lnPOP_{t-j} + \sum_{j=1}^{q} \varphi_{1,5j}\Delta lnEC_{t-j} + \varnothing_1 ECT_{t-1} + \mu_{1t} \tag{10}$$

$$\Delta lnRI_{t} = \omega_1 + \sum_{j=1}^{q} \varphi_{1,1j}\Delta lnRI_{t-j} + \sum_{j=1}^{q} \varphi_{1,2j}\Delta lnCO_{2t-j} + \sum_{j=1}^{q} \varphi_{1,3j}\Delta lnTI_{t-j}$$
$$+ \sum_{j=1}^{q} \varphi_{1,4j}\Delta lnPOP_{t-j} + \sum_{j=1}^{q} \varphi_{1,5j}\Delta lnEC_{t-j} + \varnothing_1 ECT_{t-1} + \mu_{1t} \tag{11}$$

$$\Delta lnTI_{t} = \omega_1 + \sum_{j=1}^{q} \varphi_{1,1j}\Delta lnTI_{t-j} + \sum_{j=1}^{q} \varphi_{1,2j}\Delta lnRI_{t-j} + \sum_{j=1}^{q} \varphi_{1,3j}\Delta lnCO_{2t-j}$$
$$+ \sum_{j=1}^{q} \varphi_{1,4j}\Delta lnPOP_{t-j} + \sum_{j=1}^{q} \varphi_{1,5j}\Delta lnEC_{t-j} + \varnothing_1 ECT_{t-1} + \mu_{1t} \tag{12}$$

$$\Delta lnPOP_{t} = \omega_1 + \sum_{j=1}^{q} \varphi_{1,1j}\Delta lnPOP_{t-j} + \sum_{j=1}^{q} \varphi_{1,2j}\Delta lnTI_{t-j} + \sum_{j=1}^{q} \varphi_{1,3j}\Delta lnRI_{t-j}$$
$$+ \sum_{j=1}^{q} \varphi_{1,4j}\Delta lnCO_{2t-j} + \sum_{j=1}^{q} \varphi_{1,5j}\Delta lnEC_{t-j} + \varnothing_1 ECT_{t-1} + \mu_{1t} \tag{13}$$

$$\Delta lnEC_{t} = \omega_1 + \sum_{j=1}^{q} \varphi_{1,1j}\Delta lnEC_{t-j} + \sum_{j=1}^{q} \varphi_{1,2j}\Delta lnPOP_{t-j} + \sum_{j=1}^{q} \varphi_{1,3j}\Delta lnTI_{t-j}$$
$$+ \sum_{j=1}^{q} \varphi_{1,4j}\Delta lnRI_{t-j} + \sum_{j=1}^{q} \varphi_{1,5j}\Delta lnCO_{2t-j} + \varnothing_1 ECT_{t-1} + \mu_{1t} \tag{14}$$

From the models above, ω is the constant term, while φ symbolizes the coefficients to be computed. Also, ECT_{t-1} is the error correction term with $\varnothing$ being the error correction coefficient that captures the speed of adjustment towards the equilibrium. Additionally, the difference operator is epitomized by Δ, while q is the optimal lags that are selected via the AIC. Finally, the stochastic error term which is serially uncorrelated with a mean of zero is represented by μ, while the timeframe is denoted by t.

Results and discussions

Unit root and cointegration test results

Some econometric techniques require variables to be stationary before they could yield valid outcomes. If not, there is the possibility that one will be dealing with explosive series that do not exhibit mean reversion. Therefore, as a first step, the variables' integration order is assessed via the unit root tests indicated in Table 5. From the results, the variables had an $I(1)$ order of integration. Thus, the null hypothesis of no unit root amidst the residual terms could not be rejected after the first difference. This suggests that the statistical characteristics of the series were unchanged by shifts in time. This finding aligns with that of Musah et al. (2021), Chen et al. (2022), Li et al. (2021a, b) and Bhat et al. (2021). It was also important to establish the potential association between the variables in the long term because detrending could not guarantee that there was no spurious correlation between the variables of concern. Therefore, the Johansen cointegration test was performed to examine the cointegration attributes of the series. From the discoveries of the text displayed in Table 6, the null hypothesis of no cointegration amidst the series could not be validated. This suggests that the variables were materially affiliated in the long term. Thus, the variables were so intertwined that they could not deviate from equilibrium in the long run. The finding validates the works of Musah et al. (2022b) and Li et al. (2020a, 2020b).

Regression and causality test results

Having confirmed cointegration association amidst the series, the coefficients of the predictors were explored via the FMOLS, DOLS and CCR econometric techniques. From the estimates indicated in Table 7, RI worsens EQ in Ghana through CO_2 mitigations. All other factors held constant, a 1% rise in RI deteriorated EQ by 0.096%, 0.106% and 0.079% based on results of the three estimators

Table 5 Unit root test results

Variable	ERS		PP		KPSS		ADF	
	Level	1st diff	Level	1st diff	Level	1st diff	Level	1st diff
$lnCO_2$	1.202	6.241***	2.490	−4.343**	3.499	6.320***	2.727	−5.343***
$lnRI$	4.118	5.261***	−1.142	−2.231***	0.663	5.311***	−1.165	−4.223***
$lnTI$	5.763	6.437***	−0.406	3.022*	0.156	3.337**	−2.406	0.022**
$lnPOP$	2.338	4.026**	1.951	−2.399**	0.509	1.466*	0.938	−2.310**
$lnEC$	3.553	5.206***	−0.297	−6.233***	0.441	2.256**	−0.297	−6.233***

ERS represents Elliott, Rothenberg and Stock (1996) test, *PP* represents Phillip and Perron (1988) test, *ADF* signifies Augmented Dickey and Fuller (1979) test and *KPSS* denotes Kwiatkowski-Phillips-Schmidt-Shin (1992) test

Also, ***, **, * denote significance at the 1%, 5% and the 10% levels, respectively

Table 6 Johansen cointegration test results

Unrestricted cointegration rank test (trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace statistic	5% critical value	Prob.**
None *	0.890	158.795	69.819	0.001
At most 1*	0.633	79.332	47.856	0.003
At most 2*	0.497	43.285	29.797	0.002
At most 3*	0.325	18.533	15.495	0.017
At most 4*	0.115	4.397	3.841	0.036

Unrestricted cointegration rank test (maximum eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-eigen statistic	5% critical value	Prob.**
None*	0.890	79.464	33.877	0.002
At most 1*	0.633	36.047	27.584	0.005
At most 2*	0.497	24.752	21.131	0.015
At most 3	0.325	14.136	14.265	0.052
At most 4*	0.115	4.397	3.841	0.036

The trace tests indicate 5 cointegrating equations at the 0.05 level, whilst the max-eigenvalue test indicates 4 cointegrating equations at the 0.05 level

Also, * denotes rejection of the null hypothesis at the 0.05 level, while ** represents the MacKinnon-Haug-Michelis (1999) *p*-values

correspondingly. This finding suggests that the influxes of remittances were not channelled to environment friendly activities in the country. The discovery also implies remittances did not stimulate investments in activities that could boost EQ in the country. Moreover, remittances influenced people to buy more polluting home appliances and automobiles worsened EQ in the nation. Besides, the utilization of remittances through market regulations did not help to improve the country's quality of the environment. The finding also suggests that remittances deteriorated ecological quality in the nation by escalating household consumption and savings that promote energy utilization and financial

sector development, which are key agents of pollution. Additionally, remittances worsened environmental sustainability in Ghana, because they stimulated the aggregate demand for industrial productions, which are linked to the consumption of dirty energies like fossil fuels that are ecologically damaging. Most often, high polluting foreign industries make their way into countries with many resources, but with weak environmental regulations. Ghana is one of the culprits in that, it has weak ecological measures and will therefore advocate for such industries to be established there. The positive association between RI and EQ aligns with that of Khan et al. (2020) and Jiang et al. (2020) but contrasts that of Usama et al. (2020) and Neog and Yadava (2020).

Also, TI mitigated ecological pollution in Ghana. Specifically, a 1% surge in TI improved EQ in the country by 0.076%, 0.067% and 0.087% based on the results of the three estimators, respectively. This finding means TI played an essential role in mitigating environmental pollution in the nation. Thus, promoting TI was an essential means through which ecological quality in the nation could be improved. The negative connection between TI and environmental pollution supports that of Adebayo et al. (2021a, b) who indicated that innovation paired with ecological conservation activities help to minimize the emanation of carbon. According to the authors, innovation is required for the efficient utilization and development of clean energies. Besides, advancements in technology help to boost the potential of green energies, making them available to meet energy demand (Adebayo et al. 2021a, b). The above assertion agrees with Sohag et al. (2015) and Yang et al. (2021a, b) who postulated that innovation propels the implementation of clean energies to meet energy demand and shift energy utilization from conventional to modern sources. The finding also aligns with those of Chen and Lee (2020) and Yu and Du (2019) who indicated that technology is one of the authentic means to mitigate environmental pollution and boost economic

Table 7 FMOLS, DOLS and CCR estimation results

Variable	FMOLS			DOLS			CCR		
	Coeff	t-Statistic	Prob	Coeff	t-Statistic	Prob	Coeff	t-Statistic	Prob
ln*RI*	0.096	3.627	0.003***	0.106	2.906	0.002***	0.079	1.944	0.001***
ln*TI*	−0.076	−2.418	0.021**	−0.067	−1.743	0.089*	−0.087	−2.256	0.034**
ln*POP*	1.920	3.331	0.002***	2.039	3.033	0.005***	1.965	4.128	0.002***
ln*EC*	0.119	4.039	0.003***	0.096	2.713	0.018**	0.121	4.458	0.001***
Constant	1.506	3.526	0.012***	1.444	2.817	0.001***	1.551	4.223	0.002***
R^2	0.778			0.779			0.772		
Adjusted R^2	0.753			0.755			0.746		
Observation	41			41			41		

$lnCO_2$ is the response variable, std. error stands for standard error and the long-run variance estimate (Bartlett Kernel, Newey-West fixed bandwidth) of the FMOLS, DOLS and CCR estimators = 4.0000

Finally, ***, **, * denote significance at the 1%, 5% and the 10% levels, respectively

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viability in nations. The finding further supports the assertion of Qayyum et al. (2021) that technology improves the efficiency of energy leading to CO_2 abatement. As a result, authorities should invest immensely in technology to help attain minimal environmental pollution. The study's finding is contrasting the conclusion of Raiser et al. (2017) that technology surrogated by patents aims to minimize sustainable development, and is therefore considered as a barrier to climate change abatement. Studies by Khattak et al. (2020) and Villanthenkodath and Mahalik (2020) are also conflicting with the above discovery.

Additionally, POP degraded ecological quality in Ghana. *Ceteris paribus*, a percentage surge in POP degraded EQ by 1.92%, 2.039% and 1.965% based on the results of the three estimators correspondingly. This suggests that POP played an incremental role in worsening ecological quality in the country. With the surge in POP, individuals consumed more carbon-related resources to meet their overall demands and therefore generated more CO_2 exudates in the country. Also, the upsurge in POP led to a rise in high-polluting production activities escalating the emissivities of carbon in the country. Thus, higher levels of POP had severe impacts on the emanation of carbon and posed a threat to the health of people in the nation. The Global Footprint Network (2019) estimates that 86% of the globe's population lives in an ecological deficit. As a result, the increased population puts strain on the environment by increasing carbon emission. The detrimental influence of POP on EQ supports the works of Ruzi et al. (2021) and Guoyan et al. (2021) but deviates from that of Lv and Xu (2018) and Fonchamnyo et al. (2021). Moreover, EC deteriorated Ghana's EQ. Specifically, a percentage rise in energy use promoted carbon exudates by 0.119%, 0.096% and 0.121% based on the results of the three estimators, respectively. These findings suggest that the energy used to drive economic activities in the country was not from clean sources that could help stimulate ecological quality in the nation. It is, therefore, critical for

the country to adopt renewable energy technologies to help improve its EQ. The finding aligns with those of Musah et al. (2022a) and Musah et al. (2021d) but contrasts those of Xue et al. (2021) and Sharma et al. (2020). Lastly, the adjusted R-squared values of 0.753, 0.755 and 0.746 for the three estimators imply 75.3%, 75.5% and 74.6% of the variances in the response variable were accounted for by the predictors. Comparatively, the coefficients under the three estimators in terms of the sign were the same. This justifies the robustness of the results.

At the last phase of the analysis, the causations amidst the series were determined via the Engle and Granger (1987) VECM approach. As depicted in Table 8, all the ECTs are substantially negative, implying that, a long-term association exist amidst the variables. Empirical explorations by Islam (2021a, 2021b) and Quacoe et al. (2021) are in support of the above discovery. On the short-term causalities amidst the series, there was a bidirectional causality between RI and CO_2 effusions. This means the two variables were inter-reliant on each other such that a rise in one variable led to a rise in the other variable. An exploration by Khan et al. (2020) on BRICS economies align the study's discovery; however, those by Wang et al. (2021) and Yang et al. (2021a, b) are conflicting with the above discovery. Also, there was no causality between TI and CO_2 excretions. This implies the two series were not dependent on each other. Explorations by Bashir et al. (2020) and Abid et al. (2021) agree with the revelation of this research. Moreover, POP and CO_2 emanations were mutually interrelated. This indicates that POP caused CO_2 secretions to rising and vice versa. Studies by Li et al. (2021a, b) and Naseem et al. (2021) align the study's discovery. Lastly, causation from EC to CO_2 effusions was discovered. This means, EC drove CO_2 emissivities in the country, but not the opposite. The revelation is not astounding in that Ghana is witnessing massive expansion in the industrial and agricultural sectors, among

Table 8 VECM Granger causality test results

Variable	lnCO$_2$	ln*RI*	ln*TI*	ln*POP*	ln*EC*	ECT
lnCO$_2$	-	3.848	0.567	3.545	0.198	− 0.871
		(0.003) ***	(0.423)	(0.033)**	(0.765)	(0.006)***
ln*RI*	4.476	-	5.253	4.114	0.284	− 0.576
	(0.002)***		(0.231)	(0.053)*	(0.136)	(0.002)***
ln*TI*	0.447	0.164	-	0.798	0.915	− 0.678
	(0.516)	(0.061)*		(0.426)	(0.481)	(0.041)**
ln*POP*	5.242	0.437	1.112	-	3.255	− 0.712
	(0.004)***	(0.022)**	(0.483)		(0.003)***	(0.005)***
ln*EC*	5.241	0.126	0.177	0.772	-	− 0.684
	(0.0207)**	(0.525)	(0.346)	(0.199)		(0.007)***

lnCO$_2$ is the response variable, while values in parenthesis () represent probabilities

Finally, ***, **, * denote significance at the 1%, 5% and the 10% levels, respectively

others. These expansions are executed via the utilization of emission-intensive energies that worsen environmental quality. This implies environmental quality and economic development can both improve if Ghana embraces green energy utilization. Studies by Doğanlar et al. (2021) and Ahmad et al. (2021) deviate from the discovery of the study; however, those by Musah et al. (2021a) and Li et al. (2020b) are in line with the study's disclosure.

Conclusions and policy recommendations

This exploration examined the connection amidst remittance inflows and environmental quality in Ghana from 1980 to 2020. In order to yield valid and reliable outcomes, robust econometric methods that control for endogeneity, heteroscedasticity and serial correlation among others, were engaged for the analysis. From the study's discoveries, the series was first differenced stationary and flanked by a long-term cointegration association. The elasticities of the predictors were estimated via the FMOLS, DOLS and CCR techniques, and from the findings, remittance inflows degraded ecological quality in Ghana through high carbon emissions. Also, population growth and energy utilization were not environment friendly; however, technological innovations improved ecological quality in the nation. On the causalities amidst the series, there were bidirectional causalities between remittance inflows and CO_2 effusions and between population growth and CO_2 emanations. Also, energy consumption caused CO_2 effluents, but there was no causality between technological innovations and the effludates of CO_2. From the above revelations, the study concludes that remittances inflows, population growth and energy utilization deteriorate environmental quality in Ghana; however, technological innovations improve ecological quality in the country.

Based on the above, it is recommended that, even though remittances are key agents of economic progress and financial sector developments, their adverse consequences on the environment should be seriously addressed. Authorities can attain this goal by enacting regulations to control the activities of polluting industries that are being financed by remittances. Also, households and individuals should minimize their use of remittances to finance carbon-intensive items, like automobiles and air-conditioners, among others, that add to environmental pollution in the country. If the aforestated recommendations are implemented, the damaging effects of remittances on ecological quality will be minimized, thereby stimulating sustainable development. Moreover, the government can boost ecological quality in the country by advocating for the adoption of environmentally friendly technologies in all establishments. This objective can be achieved if the

government gives incentives like tax rebates to local entities to help them import modern technologies from other parts of the world. The adverse consequences of population growth on the environment suggest that the government and policymakers should regulate the rate of population in the country. As evidenced from the study, a rise in population growth escalated the rate of emissions in the country. Therefore, if the rate of population is well regulated, it will help curtail the emanation of carbon in the country. Additionally, the government should advocate for the utilization of clean energies in all economic activities in the country. This goal can be attained by allocating substantial financial resources into research and development linked to the consumption of green energy. Thus, the pollution-free growth process targeted by authorities of the nation can be attained, if the country transitions from conventional energy sources like fossil fuels to green sources like solar and hydro among others. Furthermore, efforts to boost the energy industry should be undertaken with caution so as not to jeopardize the long-term goal of a carbon-free economy. Besides, intensifying public awareness on ecological quality, improving environmental monitoring, and applying strict ecological measures are all means through which environmental pollution in Ghana could be minimized. Furthermore, the quality of institutions in the nation should be improved, because institutional quality helps establishments to adopt green technologies, and also helps to boost public awareness of a clean environment. According to Jiang et al. (2020), green policies fail to succeed in countries due to minimal support, involvement and cohesion from key stakeholders. Therefore, policymakers should actively engage and encourage all important stakeholders to participate in the development and implementation of green policies in the country. Finally, the IEA, UN and the World Bank advise governments to embrace carbon pricing because it has a lot of benefits than other options. The government of Ghana should, therefore, include carbon pricing in its strive towards a low-carbon economy.

The limitations of this exploration cannot be overlooked. Firstly, the researcher had hoped to use a longer study period for the analysis; however, because of data constraints, the study covered the period 1980 to 2020. It is, therefore, proposed that when more data become available, comparable studies should be conducted to authenticate the study's findings. Also, the FMOLS, DOLS and CCR techniques were used to estimate the parameters of the predictors. This signposts that interpretation of the study's results warrants some caution because the adoption of other techniques might yield different results. Moreover, the study was confined to only Ghana. For comparison purposes, similar studies in different geographical locations can be conducted to help authenticate the study's outcomes. In examining the nexus amidst remittance inflows and environmental quality in Ghana, the study

controlled for technological innovations, population growth and energy utilization. It is, therefore, suggested that future explorations should control for more macroeconomic variables to help minimize OVB issues. We finally suggest that future explorations should consider adopting the quantile regression technique because it will provide information on the entire conditional distribution of environmental quality. For instance, the influence of energy consumption on ecological quality could differ at different quantiles, and it is the only estimator that can provide such information.

Abbreviations RI: Remittance inflows; TI: Technological innovations; POP: Population growth; EQ: Environmental quality; CO_2 emissions: Carbon dioxide emissions; EC: Energy consumption; DARDL: Dynamic autoregressive distributed lag; ARDL: Autoregressive distributed lag; VECM: Vector error correction model; GMM: Generalized method of moments; ECT: Error correction term; ADF: Augmented Dickey-Fuller; PP: Phillips–Perron; WDI: World Development Indicators; FMOLS: Fully modified ordinary least squares; DOLS: Dynamic ordinary least squares; OVB: Omitted variable bias; CCR: Correlated component regression; BRICS: Brazil, Russia, India, China and South Africa; SDGs: Sustainable development goals; OECD: Organisation for Economic Co-operation and Development; PCA: Principal component analysis; SD: Standard deviation; VIF: Variance inflation factor; IEA: International Energy Agency; GHG: Greenhouse gas; G-20: Group of Twenty; IMF: International Monetary Fund; CCEMG: Common correlated effects mean group; NARDL: Non-linear autoregressive distributed lag; PMG: Pooled mean group; USA: United States of America; GLS: Generalized least squares; ERS: Elliott, Rothenberg and Stock; KPSS: Kwiatkowski-Phillips-Schmidt-Shin; AIC: Akaike Information Criterion; BICS: Brazil, India, China, South Africa; PVAR: Panel vector autoregression; CUP-FM: Continuously updated fully modified; CUP-BC: Continuously updated biased-corrected; FM-LS: Fully modified least squares

Author contribution KL conceptualized the study; XW drafted the original manuscript; MM1 helped in conceptualizing the study and also helped in the analysis and discussions; YN helped in the analysis and discussions; MM2 helped in the analysis and discussions and drafting of the original manuscript; MA helped in the analysis and discussions; ZG helped to provide the data; HX helped in the analysis and discussions; XY1 helped in editing the final manuscript; XY2 helped in the analysis and discussions; KS helped to provide the data; LW helped in editing the final manuscript. All the authors read and approved the final manuscript.

Declarations

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