

Asongu, Simplice; Mensah, Barbara D.; Ngoungou, Judith

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Thresholds of external flows in financial development for environmental sustainability in sub-Saharan Africa

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A G D I Working Paper

WP/22/082

Thresholds of external flows in financial development for environmental sustainability in sub-Saharan Africa

Simplice A. Asongu

African Governance and Development Institute,
P.O. Box 8413, Yaoundé, Cameroon
E-mails: asongusimplice@yahoo.com,
asongus@afridev.org

Barbara D. Mensah

Department of Banking and Finance,
University of Professional Studies, Accra, Ghana
E-mail: barbara-deladem.mensah@upsamail.edu.gh

Judith C. M. Ngoungou

University of Yaoundé 2, Soa, Cameroon
E-mail: moujonguejudith@gmail.com

Research Department

**Thresholds of external flows in financial development for environmental sustainability
in sub-Saharan Africa**

Simplice A. Asongu, Barbara D. Mensah & Judith C. M. Ngoungou

Abstract

The study complements extant literature by assessing linkages between financial development, external flows and CO2 emissions in 27 sub-Saharan African countries for the period 2002 to 2018. The empirical evidence is based on interactive quantile regressions and external flows consist of remittances, foreign aid, trade openness and foreign investment. The findings establish minimum thresholds of external flows that are needed for the corresponding external flows to interact with financial development in view of promoting environmental sustainability by means of reducing CO2 emissions.

Keywords: foreign aid, remittances, foreign direct investment, official development assistance, trade, CO2 emissions, quantile regressions

JEL Classification: C52; O38; O40; O55; P37

1. Introduction

In recent decades, climate unpredictability induced by the ongoing accumulation of carbon emissions (CO₂ emissions) has resulted in environmental issues such as global warming and periodic outbreaks of extremely severe weather that endangers human lives (Schweinsberg et al., 2020). Combating the aforementioned threat has become a serious concern for all governments globally, attracting the attention of ecological economists as well, *inter alia*: Yang et al. (2021); Jafri et al. (2021); Majeed et al. (2020); Khan et al. (2020); Rahman et al. (2019); Wang et al. (2021); Abdul-Mumuni et al. (2022); Mensah and Abdul-Mumuni (2022). As a result, green growth and development have emerged as significant global influences in the economic system's reorganization. CO₂ emissions are rising all throughout the world. CO₂ emissions increased by 10.88% between 1980 and 1999 and by 25.49% between 2000 and 2009. Global attempts to control growing CO₂ emissions have brought some benefits. This is because global emissions increased by just 9.7% between 2010 and 2018 (World Bank, 2022). However, recent data shows that as at 2019, the amount of carbon emitted into the environment hit the highest (34,344,006 kilotons). The continuous accumulation of CO₂ emissions drew policymakers' attention to the development of the United Nations Framework Convention on Climate Change (UNFCCC) with the ultimate goal of achieving net-zero CO₂ emissions, as well as the Kyoto Protocol, which operationalizes the UNFCCC by ensuring that all 193 parties who signed the UNFCCC meet their individual targets.

Economic growth cannot be achieved in isolation from external inputs. This is because, in order to accelerate economic growth, rising economies welcome external inflows to sustain growth and satisfy finance requirements for economic operations (Wu et al., 2020). Despite their importance in encouraging economic growth, external inflows have certain environmental consequences. Based on research, the potential effects of these inflows on CO₂ emissions may be assessed from two angles. External inflows stimulate economic activity, which raises CO₂ emissions only if the energy consumed as a result of economic development comes from nonrenewable sources such as fossil fuels (Mensah & Abdul-Mumuni, 2022). Similarly, a rise in household income as a consequence of external inflows will lead to an increase in spending. However, if environmentally unfavorable items are purchased, the likelihood of increased CO₂ emissions is considerable (Mensah & Abdul-Mumuni, 2022). External inflows, on the other hand, have the ability to reduce CO₂ emissions by assisting the industrial sector in transitioning from an outmoded approach to an updated technical system (Ikegami & Wang, 2021). As a result, foreign inflows help firms

replace outmoded technology with modern ones that consume less energy and hence generate less carbon. This is because technological innovation helps in the growth of renewable energy as well as enhances countries' use of renewable resources to make industrial and economic activities more sustainable, therefore providing as a feasible option for CO₂ emissions reduction. The linkage between economic growth and CO₂ emissions has been extensively addressed through the Environmental Kuznets Curve (EKC) hypothesis which proposes that during the early stages of economic growth, countries prioritize economic prosperity over environmental issues but as income increase, countries tend to employ renewable energy resources as well as import products that are highly polluting rather than producing them to reduce CO₂ emissions. Recently, few studies have adjusted the EKC by including variables such as external inflows (Foreign Direct Investment-FDI, Remittances, Official Development Assistance-ODA, Trade Openness) (Mensah & Abdul-Mumuni, 2022; Abdul-Mumuni et al., 2022; Wang & Zhang, 2021; Wang et al., 2022). This implies that with advanced eco-friendly technologies resulting from external inflows, countries may be more environmentally conscious and reduce CO₂ emissions.

Other researchers have also cited that financial development has a role to play in the external inflow- CO₂ emissions nexus. Thus, researchers on financial development have been able to link the impact of external inflows into countries on CO₂ emissions in the presence of improved financial development. For example Khan and Ozturk (2021) reported that improved financial development help reduce the adverse effect of trade openness on environmental quality. Yang et al. (2020) and Yang et al. (2021) also posited that the attainment of remittance-CO₂ emissions reduction targets is realizable through improved financial development. The above is consistent with Arogundade et al. (2022) who found a negative nexus in the moderation effect of financial development on the impact of remittances on CO₂ emissions. From the foregoing, it can be concluded that improved financial development is not only a necessary condition but a sufficient condition to attain external inflow- CO₂ emissions reduction targets.

Of the highlighted studies in the extant literature, the closest to the positioning of the present study is Mensah and Abdul-Mumuni (2022) which has used a Nonlinear Autoregressive Distributed Lag (NARDL) approach to assess nexuses between remittances, financial development and CO₂ emissions in sub-Saharan Africa. The findings of the study have revealed that, *inter alia*, financial development and remittances asymmetrically affect CO₂ emissions in the sub-region. Moreover, the long term positive shock in remittances on CO₂

emissions is of higher magnitude compared to the negative shock in remittance while both negative and positive shocks in financial development reduce CO2 emissions. The main similarity between the present study and Mensah and Abdul-Mumuni (2022) is that, there is an assessment of how remittances and financial development influence CO2 emissions. Beyond this similarity, a plethora of distinctive features below is also apparent.

- (i) Contrary to the underlying study, the present study defines financial development and remittances in terms of channel and policy variables, such that, the main channel is financial development while remittances are considered as an external flow. The specifications are also tailored to provide critical levels of remittances in the favorable incidence of financial development on CO2 emissions.
- (ii) The present study goes beyond the adoption of remittances as the only external flow by considering foreign aid, trade openness and foreign direct investment as complementary external flows to remittances in order to avail room for more policy implications.
- (iii) The periodicity and methodology are different, *inter alia*, because the present study is based on quantile regressions in order to assess the investigated linkages throughout the conditional distribution of CO2 emissions. Accordingly, contrary to the underlying study, we argue in the present exposition that blanked policies from the investigated nexuses on CO2 emissions are unlikely to succeed unless such policies are contingent on initial levels of CO2 emissions and hence, tailored differently across countries with low, intermediate and high initial levels of CO2 emissions. The quantile regressions estimation strategy addresses the attendant concern of accounting for initial levels of CO2 emissions.
- (iv) On the policy front, the present exposition still argues that while nexuses between the independent variables of interest and the outcome variable are worthwhile for policy implications, providing policy makers with actionable thresholds of the moderating variables that are relevant to influence the investigated linkages in the favorable direction, is even more worthwhile. Hence in order to address the concern, the study provides external flow policy thresholds that are relevant in tailoring the “financial development”-“CO2 emissions” nexus to be consistent with

environmental sustainability. This is achieved within the framework of interactive regressions which has been documented in the contemporary environmental sustainability literature to provide policy thresholds and/or thresholds for complementary policies in order to enhance room for policy implications (Asongu & Odhiambo, 2021).

The rest of the study is organized as follows. The relevant literature is covered in Section 2 while Section 3 outlines the data and methodology. Section 4 presents and discusses the findings while Section 5 concludes with policy implications and future research directions.

2. Literature review

Climate change resulting from human and industrial actions continues to diminish environmental quality. Among other dynamics, remittances, trade openness, ODA, FDI and financial development have been acknowledged as factors that have influence on CO2 emissions. For a better understanding, the studies are grouped into four research clusters respectively on the relationships among (i) financial development, remittances and CO2 emissions (ii) financial development, trade and CO2 emissions (iii) financial development, ODA and CO2 emissions (iv) financial development, FDI and CO2 emissions

(i) Financial development, remittance and CO2 emissions nexus

Scholars have done several studies using various models and samples to give empirical evidence for the link among remittances, financial development and CO2 emissions. Nevertheless, these studies do not yet establish a consensus. In general, the empirical literature supports three primary points of view: remittances and financial development decrease CO2 emissions, increase CO2 emissions, and alternative perspectives. From a panel perspective, Mensah and Abdul-Mumuni (2022) in exploring the asymmetric effect of remittances and financial development on CO2 emissions in Sub-Saharan Africa revealed that both negative and positive shocks of financial development decrease CO2 emissions while those of remittances increase CO2 emissions. Wang et al. (2021) revealed that financial development insignificantly increases CO2 emissions while remittances significantly decrease CO2 emissions in India, Philippines, Egypt, Pakistan and Bangladesh from 1980 to 2016 via the Autoregressive Distributed Lag (ARDL) model. Yang et al. (2020) initiated that both remittances and financial development spur significant increment in CO2 emissions in their study from a global space of 97 countries using the system Generalized Methods of Moments (GMM). However, the interactive effect of financial development was found to be

negative. Also, Jamil et al. (2022) revealed that remittances decrease CO₂ emissions in G-20 countries from 1990 to 2019 using the Fully Modified Ordinary Least Square (FMOLS) and Dynamic Ordinary Least Square (DOLS) estimators. Furthermore, Yanget al. (2021) found evidence that financial development and remittances contribute to CO₂ emissions in Brazil, India, China and South Africa from 1990 to 2016. In addition, studying the moderating role of financial development in the remittance-CO₂ emissions nexus, the aforementioned authors concluded that remittances decrease CO₂ emissions. Finally, Arogundade et al. (2022) found evidence that the moderation effect of financial development on the impact of remittances on CO₂ emissions is negative for 22 African countries from 1990 to 2017 via the panel quantile regression approach.

(ii) Financial development, trade and CO₂ emissions nexus

The influence of international commerce on environmental sustainability is a critical component in trade policy formulation. Numerous studies have recently been undertaken on the dynamic interconnectivity between trade openness and CO₂ emissions. Nonetheless, empirical results are varied. Sohag et al. (2017), for example, used data from 82 developing countries between 1980 and 2012 to evaluate the effects of real income, trade, population growth, and energy consumption on CO₂ emissions using multiple mean group (MG) techniques (cross-correlated and augmented). The findings revealed that trading decreases carbon pollution. Meanwhile, the results for low-income, middle-income, and full-sample nations were equivocal. Zhang et al. (2017) examined the impact of trade openness on CO₂ emissions from 1971 to 2013 using data from ten newly industrialized nations. The authors employed contemporary panel methodologies, and their findings suggested that trade openness had a negative impact on CO₂ emissions, implying that increased trade openness reduces environmental deterioration in the countries analyzed. Khan and Ozturk (2021) employed the GMM approach and reported that financial development decreases the negative effect of trade openness on CO₂ emissions in 88 developing countries from 2000 to 2014. Also, Wang and Zhang (2021) conducted similar study from the global perspective for 182 countries from 1990 to 2015. They revealed that trade decreases CO₂ emissions in upper-middle and high income countries whereas having no significant incidence on carbon emissions of lower-middle income countries. However, for low income countries, trade openness increases CO₂ emissions. Trade openness is inversely related to carbon emissions in 17 Central and Eastern European countries from 1994 to 2014 (Ho & Lyke, 2019). Regarding the asymmetry effect of trade openness on CO₂ emissions in Sweden from 1965

to 2019, Adebayo et al. (2022) revealed that trade openness reduces CO₂ emissions in low and medium quantiles using the quantile on quantile regression method.

Musah et al. (2021), on the other hand, studied the CO₂ emissions-trade openness relationship in eight developing (D8) nations using a dataset spanning the years 1990 to 2016. The dynamic common correlated effects mean group (DCCEM) and augmented mean group (AMG) estimators were used to investigate the relationship, and the empirical results indicated that trade openness promotes environmental degradation; while the causality test results demonstrated a bidirectional CO₂ emissions-trade openness causal correlation. Mutascu (2018) used time-frequency analysis to investigate the trade openness-CO₂ emissions relationship and discovered a negligible relationship at all frequencies. Similarly, the frequency domain causality test indicated a negligible causal connection between trade openness and CO₂ emissions. Furthermore, Zamil et al. (2019) examined the impact of trade openness on CO₂ emissions in Oman using a dataset spanning from 1972 to 2014. They used the ARDL technique, and their findings demonstrated a favorable relationship between trade openness and CO₂ emissions. Mutascu and Sokic (2020) discovered using the wavelet test that trade openness reduces CO₂ emissions in the European Union between 1960 and 2014. Furthermore, the results of the multiple and partial wavelet tests indicated that trade openness had a considerable influence on CO₂ emissions. Sun et al. (2019) found for 49 high emission countries that trading with the global world significantly increases CO₂ emissions in Belt and Road, developed, developing, undeveloped, Southeast Asia, Central Asia, Middle East, Africa and South Asia panels. However, there is an inverse relationship between trade and CO₂ emissions in East Asia and Europe. The authors utilized data from 1991 to 2014 and the FMOLS estimator for their analysis.

(iii) Financial development, ODA and CO₂ emissions nexus

Investigations on the relationship between ODA and CO₂ emissions abound in the literature with many authors showing different conclusions. With regards to panel studies for instance, using the dynamic panel threshold regression model, Wang et al. (2022) investigated the effect of ODA on CO₂ emissions for 59 low income and lower-middle income countries from 2005 to 2015 while employing urbanization as a threshold variable. They found that ODA increases CO₂ emissions. Contrarily, Sharmat et al. (2019) revealed that ODA decreases CO₂ emissions while financial development (domestic credit to private sector as a percentage of GDP) increases CO₂ emissions. Also, Lee et al. (2020) analyzed the impact of ODA on growth and CO₂ emissions in 30 recipient countries of Korea from 1993 to 2017.

Using the modified impact, population, affluence and technology (IPAT) model and simultaneous equation models (SEM), they indicated that ODA directly and indirectly reduces CO₂ emissions. Finally, Li et al. (2021) investigated the impact of green ODA on CO₂ emissions in 86 green ODA recipient countries from 2003 to 2014 using the two step system GMM. They reported that green ODA has no direct link with CO₂ emissions reduction however; they found a significant effect of institutional quality on the effectiveness of green ODA on CO₂ emissions. More specifically, in countries with low institutional quality, green ODA increases CO₂ emissions.

(iv) Financial development, FDI and CO₂ emissions nexus

The impact of FDI on CO₂ emissions has been a contentious subject in recent decades. In theory, depending on whether dimension is dominant, FDI can have a beneficial or detrimental influence on the environment (Shahbaz et al., 2018). As a result, the effect of FDI on CO₂ emissions might vary and the empirical data reveals varied effects (Shahbaz et al., 2018). For example, Muhammad and Khan (2021) used the GMM and the fixed effects model to investigate a panel of 170 nations worldwide and concluded that FDI increased CO₂ emissions. Furthermore, Guoyan et al. (2022) used the panel smooth transition regression model (PSTR) to investigate the nonlinear relationship between FDI and CO₂ emissions in Middle East North Africa (MENA) countries. The authors observed that increasing FDI boosts CO₂ emissions in a low regime, but when the economy advances to a high regime, the connection between the two variables becomes negative and substantial. These authors' empirical findings are comparable to the findings of Minh (2020) for Vietnam from 1990 to 2015, which revealed evidence that FDI inflows contribute moderately to environmental deterioration in both the short and long run using ARDL models. In the context of India, a recent research by Zameer et al. (2020) discovered that FDI has a beneficial influence on CO₂ emissions which contributes to the destruction of their environment. Furthermore, Shinwari et al. (2022) investigated how China's FDI affect CO₂ emissions in 35 Belt and Roads Initiative nations from 2000 to 2019. They found that whereas other nations' FDI raised CO₂ emissions in these countries, China's FDI reduced CO₂ emissions. Xie et al. (2020) discovered evidence that FDI can cause an increase in CO₂ emissions.

Bhujabal et al. (2021), on the other hand, used the pooled mean group (PMG) and Dumitrescu-Hurlin (D-H) panel causality to assess the influence of ICT and FDI on environmental pollution in key Asia Pacific nations. The findings demonstrated that ICT and FDI had a detrimental impact on environmental contamination. Furthermore, Mahadevan and

Sun (2020) claim that overall inward FDI into China has a pollution-reducing impact in the western and eastern areas while remaining constant in the central region. Hille et al. (2019) used the SEM to examine similar relationship for 16 provinces in the Republic of Korea and found that FDI inflows drive regional economic growth while lowering CO₂ emissions between 2000 and 2011. Duodu et al. (2021) used system GMM to explore the link between FDI and environmental quality in 23 Sub-Saharan African nations, taking into consideration policies and institutions for environmental sustainability. The findings demonstrated that FDI increases environmental quality over time.

As revealed by extant literature, although there are many studies on the relationship among financial development, external inflows and CO₂ emissions, most of such studies failed to establish minimum thresholds of external flows that are needed for the corresponding external flows to interact with financial development in view of reducing CO₂ emissions. This therefore provides grounds for the re-investigation.

3. Data and analysis

3.1 Data

The outcome variable is environmental sustainability represented by CO₂ emissions measured in kilotons. The choice of the outcome variable is based on contemporary literature (Mensah et al., 2022; Asongu et al., 2019). The main regressor channel, financial development is represented by the composite financial development index (access, depth and efficiency) based on literature (Mensah et al., 2022). The threshold variables are: (i) trade openness measured as imports and exports expressed as a percentage of GDP, (ii) international remittances received (current \$US) as a percentage of GDP, (iii) net official development assistance as a percentage of GDP and (iv) foreign direct investment as a percentage of GDP. The choice of attendant moderating or external flow variables is informed by the literature covered in Section 2, *inter alia*, Wang and Zhang, (2021), Mensah et al. (2022); Wang et al. (2022) and Abdul-Mumuni et al. (2022). The control variables employed are: renewable energy consumption as a percentage of total final energy consumption, real GDP per capita (measured in US constant 2015) (representing income), government effectiveness representing institutional quality, mobile phones representing information and communication technology (ICT) and population growth. In accordance with the engaged literature in Section 2, concerning the expected signs, while GDP per capita and population growth are anticipated

to increase CO₂ emissions, mobile phone penetration, government effectiveness and renewable energy consumption are expected to have the opposite effect.

Apart from data on financial development which were collected from the database of International Monetary Fund (IMF), data on all other variables were sourced from the World Development Indicators (WDI) online database of the World Bank (2022). The study utilized a balanced panel data on twenty-seven (27) sub-Saharan Africa countries from 2002 to 2018 based on availability of data. The definitions of the variables and their corresponding sources are disclosed in Appendix 1 while the summary statistics is provided in Appendix 2. The latter informs that study whether the computed thresholds make economic sense and are policy-relevant, not least, because in order for the external flows policy thresholds to be relevant for policy makers, the attendant thresholds should be within the policy range disclosed in the summary statistics. Appendix 3 discloses the corresponding correlation matrix.

3.2 Methodology

In accordance with the elements discussed in the introduction, the objective of the present research is to assess nexuses between external flows (remittances, foreign aid, foreign investment and trade), financial development and carbon emissions by articulating initial levels of CO₂ emissions. Accordingly, the quantile regressions (QR) estimation approach is adopted to address the underlying objective because it is an empirical strategy that is tailored to emphasize low, intermediate and high initial levels of the outcome variable, in order to provide more options for policy decision-making (Billger & Goel, 2009; Tchamyou & Asongu, 2017; Boateng *et al.*, 2018). It is worthwhile to emphasize that the adoption of the corresponding empirical approach is also to depart from Mensah and Abdul-Mumuni (2022) which is based on the NARDL approach to assess linkages between remittances, financial development and CO₂ emissions. As clarified in the introduction, compared to the NARDL technique, an interactive quantile regressions approach has a double advantage of: (i) assessing the nexuses throughout the conditional distribution of the outcome variable and (ii) establishing results with actionable policy thresholds that policy makers can directly leverage upon in order to promote environmental sustainability.

It is also important to clarify that, relative of the ordinary least squares (OLS) technique that is grounded on position that the errors that normally distributed, with the QR technique, the

underpinning assumption is not necessary, not least, because the assessment is done at various distributional points of the outcome variable. Accordingly, in the light of extant contemporary and non-contemporary QR-centric literature (Koenker & Bassett, 1978; Keonker & Hallock, 2001; Asongu, 2017), it is not necessary to perform stationarity tests when modeling by QR, not least, because: (i) the stationarity tests are employed with considering non-stationary time and panel series and (ii) QR should be performed on the level series of the variables instead of the first difference.

In the light of the adopted estimation approach, , the θ^{th} quantile estimator of CO2 emissions is obtained by solving for the optimization problem in Equation (1), that is disclosed in the absence subscripts for simplicity of presentation.

$$\min_{\beta \in R^k} \left[\sum_{i \in \{i: y_i \geq x_i' \beta\}} \theta |y_i - x_i' \beta| + \sum_{i \in \{i: y_i < x_i' \beta\}} (1 - \theta) |y_i - x_i' \beta| \right], \quad (1)$$

where $\theta \in (0,1)$. Relative to the OLS approach that is primarily based on the sum of squared residuals, estimation by quantile regression consists of maximising of absolute deviations of attendant quantiles. As a case in point, in the corresponding approach, a multitude of quantiles such as the 25th quantile or the 90th (respectively, corresponding to $\theta=0.25$ or 0.90) are estimated by approximately weighing the residuals. The corresponding conditional quantile of CO2 emissions or y_i given x_i is:

$$Q_y(\theta / x_i) = x_i' \beta_\theta \quad (2)$$

where in the relative θ th quantile that is examined, parameters are assessed for unique slopes. The corresponding formulation is parallel to $E(y / x) = x_i' \beta$ within the framework of the OLS slope for which, parameters are largely examined at the average of the conditional distribution of CO2 emissions. For the model in Eq. (2), the dependent variable y_i is CO2 emissions while x_i contains a constant term, *financial development*, *remittances*, *foreign aid*, *foreign direct investment*, *trade openness*, *renewable energy*, *income per capita*, *government effectiveness*, *mobile phones* and *population*.

4. Empirical results

4.1 Presentation of results

The empirical findings are disclosed in this section in Tables 1-2. Table 1 focuses on nexuses between remittances, foreign aid, financial development and CO2 emissions while Table 2 is concerned with linkages between foreign investment, trade openness, financial development and CO2 emissions. Each of the tables is divided into two main panels, with each panel focusing on an external flow. For instance, the left-hand side of Table 1 is concerned with remittances as external flow while the corresponding right-hand side focuses on foreign aid or official development assistance. Correspondingly, the left-hand side of Table 2 is concerned with trade openness whereas the right-hand articulates foreign direct investment. Moreover, it is also worthwhile to articulate that the choice of the QR technique is justified on the bases of variations in the significance and magnitude of estimated coefficients between OLS findings and QR results.

In order to assess the objective of this study which to provide policy thresholds of external flows, needed for an environmentally-friendly nexus between financial development and CO2 emissions, two conditions are necessary: (i) the conditional and unconditional effects of the examined channel or financial development should be significant and (ii) the conditional effect should be negative while the corresponding unconditional incidence should be positive. It follows that in the light of negative interactive estimates from the conditional effects, there are critical levels of external flows that are needed for the main channel to mitigate CO2 emissions. When these two conditions are met in the light of the context of this study: (i) thresholds are computed, (ii) 'na' or 'not applicable' is assigned to linkages in which at least one estimated coefficient needed for the computation of thresholds is not significant and (iii) 'nsa' or 'not specifically applicable' is used for pairs of estimated coefficients that are significant with the same sign.

With the above underpinnings clearly articulated, the present study is consistent with contemporary interactive regressions literature (Tchamyou, 2019, 2020; Nchofoung & Asongu, 2022a, 2022b; Nchofoung *et al.*, 2021, 2022) in the computation of thresholds in order to avoid pitfalls of interactive regressions documented by Brambor et al. (2006). According to the underlying interactive-centric literature, such computation entails both the conditional and unconditional incidences of the main channels contingent on the moderating variables. The main channel in the context of this study is financial development while the moderating variables are external flow dynamics of remittances, foreign aid, trade openness and foreign direct investment.

To put the above computational insights into more perspective, illustrative examples are worthwhile in order to enhance readability and flow. For instances: (i) in the second column of Table 1, ‘na’ or ‘not applicable’ is assigned to the space provided for thresholds because at least one estimated coefficient (i.e. the interactive effect) needed for the computation of the corresponding threshold is not significant; (ii) in the seventh column of Table 1 ‘nsa’ or ‘not specifically applicable’ is used because both the unconditional and conditional incidences of financial development have a positive sign (i.e. the same sign) and (iii) in the last column of Table 1, the official development threshold needed to reverse the positive incidence of financial development on CO2 emissions is 29.192 (12.621/0.420) % of GDP. It follows that when official development assistance is 29.192 % of GDP, the overall net effect of financial development on CO2 emission is $0.000 = ([29.192 \times -0.420] + [12.621])$. Hence, above the development assistance 29.192 (% GDP) thresholds, the overall incidence on CO2 emissions becomes negative. It follows that above, the attendant thresholds; foreign aid moderates financial development to promote environmental sustainability by means of reducing CO2 emissions. In the corresponding computation, -0.420 is the unconditional or interactive effect of financial development while 12.621 is the unconditional incidence of financial development. Moreover, in order for the established thresholds to be policy-relevant and make economic sense, they should be within statistical range. This is the case with the 29.192 (% of GDP) foreign aid threshold because it is between the minimum (-0.249) and maximum (39.431) limit disclosed in the summary statistics or Appendix 2.

The following findings can be established from Tables 1-2: (i) For foreign aid to moderate financial development to reduce CO2 emissions, foreign aid thresholds of 6.741(% of GDP), 35.444(% of GDP) and 29.192 (% of GDP) are relevant for the 25th, 75th and 90th quantiles, respectively. (ii) In order for trade openness to moderate financial development and reduce CO2 emissions, trade thresholds of 134.912(% of GDP), 104.634(% of GDP), 93.361(% of GDP), 110.421(% of GDP) and 112.958(% of GDP) are relevant for respectively, the 10th, 25th, 50th, 75th and 90th quantiles. (iii) Looking at FDI, FDI 14.704(% of GDP), 13.801 (% of GDP) and 25.281 (% of GDP) thresholds are required in order for FDI to reduce CO2 emissions by means of financial development in the 10th, 25th and 50th quantiles, respectively. All the computed thresholds are within policy-range and the most of the significant control variables have the expected signs in relation to the narrative of the data section.

Table 1: Remittances, foreign aid, financial development and carbon emissions

	Dependent variable: carbon emissions in kilotons(ln)											
	Remittances (Remi)						Official Development Assistances (ODA)					
	OLS	Q.10	Q.25	Q.50	Q.75	Q.90	OLS	Q.10	Q.25	Q.50	Q.75	Q.90
Constant	2.362*** (0.000)	3.952*** (0.000)	2.381*** (0.001)	1.921*** (0.000)	3.263*** (0.000)	3.457*** (0.000)	3.493*** (0.000)	4.638*** (0.000)	5.213*** (0.000)	3.168*** (0.000)	3.990*** (0.000)	4.277*** (0.000)
FD	11.426*** (0.000)	0.042*** (0.949)	7.575*** (0.000)	12.387*** (0.000)	12.190*** (0.000)	11.954*** (0.000)	10.376*** (0.000)	1.289 (0.183)	1.982*** (0.008)	10.720*** (0.000)	12.051*** (0.000)	12.261*** (0.000)
Remi	-0.086 (0.105)	-0.189 (0.000)	-0.005 (0.945)	-0.058 (0.276)	-0.083 (0.282)	-0.202*** (0.000)	---	---	---	---	---	---
ODA	---	---	---	---	---	---	-0.065*** (0.000)	-0.148*** (0.000)	-0.085*** (0.000)	-0.085*** (0.001)	-0.093*** (0.000)	-0.086*** (0.000)
FD× Remi	-0.006 (0.983)	0.042 (0.834)	-0.592 (0.165)	-0.467 (0.119)	0.662 (0.127)	1.679*** (0.000)	---	---	---	---	---	---
FD× ODA	---	---	---	---	---	---	-0.500*** (0.000)	-0.037 (0.838)	-0.294** (0.034)	-0.310 (0.134)	-0.340** (0.034)	-0.420*** (0.007)
Renegy	-0.021*** (0.000)	-0.044*** (0.000)	-0.025*** (0.006)	-0.026*** (0.000)	-0.035*** (0.000)	-0.042*** (0.000)	-0.009** (0.034)	-0.010 (0.104)	-0.010** (0.043)	-0.006 (0.390)	-0.021*** (0.000)	-0.021*** (0.000)
Income	0.965*** (0.000)	1.220*** (0.000)	1.003*** (0.000)	1.018*** (0.000)	1.429*** (0.000)	1.623*** (0.000)	0.803** (0.000)	0.836*** (0.000)	0.708*** (0.000)	0.771*** (0.000)	1.193*** (0.000)	1.291*** (0.000)
Gov. E.	-0.747*** (0.000)	0.194* (0.092)	-0.436* (0.072)	-0.947*** (0.000)	-0.876*** (0.000)	-0.774*** (0.000)	-0.317*** (0.008)	0.388** (0.023)	0.133 (0.302)	-0.581*** (0.003)	-0.523*** (0.000)	-0.482*** (0.001)
Mobile	0.003** (0.022)	0.007*** (0.000)	0.007*** (0.002)	0.003* (0.064)	-0.001 (0.663)	-0.003** (0.017)	-0.001 (0.280)	0.001 (0.300)	0.001 (0.339)	-0.00007 (0.972)	-0.004*** (0.004)	-0.003** (0.016)
Population	0.507*** (0.000)	0.438*** (0.000)	0.464*** (0.009)	0.628*** (0.000)	0.095 (0.597)	0.098 (0.334)	0.515*** (0.000)	0.318** (0.010)	0.253*** (0.007)	0.496*** (0.000)	0.257** (0.018)	0.145 (0.165)
Thresholds	na	na	na	na	Na	Nsa	20.752	na	6.741	Na	35.444	29.192
R ² /Pseudo R ²	0.466	0.305	0.251	0.204	0.272	0.504	0.595	0.375	0.363	0.286	0.374	0.553
Fisher	37.14***						62.28***					
Observations	459	459	459	459	459	459	459	459	459	459	459	459

*, **, ***: significance levels of 10%, 5% and 1% respectively. OLS: Ordinary Least Squares. R² for OLS and Pseudo R² for quantile regression. Lower quantiles (e.g., Q 0.1) signify nations where carbon emission is least. CO2: Carbon emissions. F.D: Financial Development. Remi: Remittances. ODA: Official Development Assistance. FDI: Foreign Direct Investment. Renegy: Renewable Energy. Income: GDP per capita. Gov.E: Government Effectiveness. Mobile: mobile phones. na: not applicable because at least one estimated coefficient needed for the computation of threshold is not significant. nsa: not specifically applicable because a synergy effect is apparent.

Table 2: Trade, FDI, financial development and carbon emissions

	Dependent variable: carbon emissions in kilotons(ln)											
	Trade Openness (Trade)						Foreign Direct Investment (FDI)					
	OLS	Q.10	Q.25	Q.50	Q.75	Q.90	OLS	Q.10	Q.25	Q.50	Q.75	Q.90
Constant	6.437*** (0.000)	-0.453 (0.594)	3.918*** (0.000)	7.593*** (0.000)	8.673*** (0.000)	8.980*** (0.000)	2.758*** (0.000)	1.303* (0.077)	1.051* (0.056)	1.989*** (0.007)	3.452*** (0.000)	2.934*** (0.000)
FD	20.147*** (0.000)	26.173*** (0.000)	20.613*** (0.000)	18.859*** (0.000)	17.557*** (0.000)	18.977*** (0.000)	12.686*** (0.000)	12.793*** (0.000)	13.001*** (0.000)	13.020*** (0.000)	12.839*** (0.000)	13.986*** (0.000)
Trade	0.014*** (0.000)	0.040*** (0.000)	0.026*** (0.000)	0.018*** (0.000)	0.007*** (0.004)	0.008** (0.034)	---	---	---	---	---	---
FDI	---	---	---	---	---	---	0.051 (0.120)	0.139*** (0.000)	0.136*** (0.000)	0.059* (0.084)	-0.039* (0.066)	-0.030 (0.256)
FD× Trade	-0.180*** (0.000)	-0.194*** (0.000)	-0.197*** (0.000)	-0.202*** (0.000)	-0.159*** (0.000)	-0.168*** (0.000)	---	---	---	---	---	---
FD× FDI	---	---	---	---	---	---	-0.458* (0.071)	-0.870*** (0.000)	-0.942*** (0.000)	-0.515*** (0.008)	0.047 (0.696)	0.089 (0.565)
Renegy	-0.003 (0.495)	0.033*** (0.000)	-0.008 (0.337)	-0.010 (0.122)	-0.003 (0.409)	0.004 (0.436)	-0.011** (0.021)	0.006 (0.445)	-0.015** (0.017)	-0.018** (0.028)	-0.026*** (0.000)	-0.029*** (0.000)
Income	-0.241** (0.019)	-0.153 (0.447)	0.067 (0.769)	-0.169 (0.362)	-0.211** (0.042)	-0.304* (0.052)	0.614*** (0.000)	0.386* (0.067)	0.806*** (0.000)	0.788*** (0.000)	1.169*** (0.000)	1.482*** (0.000)
Gov. E.	-0.309** (0.031)	0.484** (0.014)	0.101 (0.650)	-0.293 (0.104)	-0.608*** (0.000)	-0.544*** (0.000)	-0.600*** (0.000)	0.471** (0.039)	-0.273 (0.107)	-0.805*** (0.000)	-1.057*** (0.000)	-0.835*** (0.000)
Mobile	0.006*** (0.000)	0.002 (0.276)	0.007*** (0.002)	0.007*** (0.000)	0.003*** (0.000)	0.004*** (0.006)	0.003*** (0.009)	0.002 (0.347)	0.005*** (0.001)	0.004* (0.087)	-0.0004 (0.754)	0.001 (0.442)
Population	0.190** (0.047)	0.505*** (0.000)	0.367** (0.025)	-0.103 (0.433)	-0.227*** (0.002)	-0.341*** (0.002)	0.523*** (0.000)	0.607*** (0.000)	0.700*** (0.000)	0.657*** (0.000)	0.147 (0.159)	0.015 (0.908)
Thresholds	111.927	134.912	104.634	93.361	110.421	112.958	26.156	14.704	13.801	25.281	Na	Na
R ² /Pseudo R ²	0.607	0.301	0.314	0.320	0.441	0.583	0.465	0.227	0.239	0.175	0.284	0.484
Fisher	99.44***						39.36***					
Observations	459	459	459	459	459	459	459	459	459	459	459	459

*, **, ***: significance levels of 10%, 5% and 1% respectively. OLS: Ordinary Least Squares. R² for OLS and Pseudo R² for quantile regression. Lower quantiles (e.g., Q 0.1) signify nations where carbon emission is least. CO2: Carbon emissions. F.D: Financial

Development. Remi: Remittances. ODA: Official Development Assistance. FDI: Foreign Direct Investment. Renergy: Renewable Energy. Income: GDP per capita. Gov.E: Government Effectiveness. Mobile: mobile phones. na: not applicable because at least one estimated coefficient needed for the computation of threshold is not significant

The nexus of the findings with the extant literature can be discussed in four main strands pertaining to the roles of financial development, remittances, foreign aid, trade and FDI in CO₂ emissions. First, the positive unconditional effect of financial development is broadly consistent with the strand of literature on the positive incidence of financial development on CO₂ emissions (Yang et al., 2020, 2021) while contrary to the corresponding strand on the negative incidence of financial development on CO₂ emissions (Khan & Ozturk, 2021; Arogundade et al., 2022), yet counteracting to the strand of literature which has established no significant nexus between financial development and CO₂ emissions (Wang et al., 2021).

Second, with respect to remittances, the overwhelming insignificant moderating effect of remittances in the nexus between financial development and CO₂ emissions is contrary to Mensah and Mumuni (2022) who have established that both remittance and financial development engender negative and positive shocks. However at the 90th quantile of CO₂ emissions, the positive interactive effect between remittance and financial development in the combined effect on CO₂ emissions is contrary to the stream of literature on remittances reducing CO₂ emissions (Jamil et al., 2022) while consistent with the stream on remittance positively influencing CO₂ emissions. Third, the overwhelming moderating role of trade openness is consistent with the strand of globalization literature positing for a favorable role of trade in reducing CO₂ emissions (Sohag et al., 2017; Zhang et al., 2017; Ho & Lyke, 2019; Khan and Ozturk, 2021; Wang & Zhang, 2021; Adebayo et al., 2022) while inconsistent with the strand on the trade promoting CO₂ emissions (Zamil et al., 2019; Sun et al., 2019).

Fourth, the favorable moderating incidence of foreign aid, though contingent on quantiles, it is contrary to the strand of studies on the positive incidence of official development assistance on CO₂ emissions (Wang et al., 2022), but consistent with the stand on the role of foreign aid in reducing CO₂ emissions (Sharmat et al., 2019; Lee et al., 2020). Fifth, the appealing moderating effect of FDI in bottom quantiles of the CO₂ emissions distribution confirms findings on the rewarding role FDI in mitigating CO₂ emissions (Hille et al. (2019; Mahadevan & Sun, 2020; Bhujabal et al., 2021; Duodu et al., 2021) while negating studies which have suggested the contrary (Minh, 2020; Zameer et al., 2020; Xie et al., 2020; Muhammad & Khan, 2021).

5. Concluding implications and future research directions

The study has complemented that extant literature by assessing linkages between financial development, external flows and CO₂ emissions in 27 sub-Saharan African countries for the period 2002 to 2018. The empirical evidence is based on interactive regressions and external flows consist of remittances, foreign aid, trade openness and foreign investment. The findings have established thresholds of external flows that are needed for the corresponding external flows to interact with financial development in view of promoting environmental sustainability by means of reducing CO₂ emissions. Minimum levels of the relevant external flows or policy thresholds are: (i) foreign aid critical levels of 6.741(% of GDP), 35.444(% of GDP) and 29.192 (% of GDP) are relevant for the 25th, 75th and 90th quantiles, respectively; (ii) trade openness thresholds of 134.912(% of GDP), 104.634(% of GDP), 93.361(% of GDP), 110.421(% of GDP) and 112.958(% of GDP) for respectively, the 10th, 25th, 50th, 75th and 90th quantiles and (iii) FDI thresholds 14.704(% of GDP), 13.801 (% of GDP) and 25.281 (% of GDP) in the 10th, 25th and 50th quantiles, respectively.

In terms of policy implications, the findings of interactive regressions can double as policy implications when the findings report actionable critical levels of the moderating or policy variables that policy makers can build upon to influence how the considered channels influence the outcome variable. Within the remit of the this study, we have provided critical or minimum levels of foreign aid, foreign direct investment and trade openness needed in order for financial development to promote environmental sustainability through CO₂ emission reduction. These critical levels of external flows are contingent on existing or initial levels of CO₂ emissions.

The study obviously leaves space for future research, especially in view of considering how the considered external flows and financial development influence sustainable development outcomes beyond the remit of promoting environmental sustainability by means of reducing CO₂ emissions. This is essentially because, environmental sustainability is among a plethora of sustainable development objectives articulated by the United Nations for the 2030 sustainable development agenda. Moreover, it is also worthwhile to engage country-specific studies with the relevant estimation techniques for the achievement of more country-specific policy implications.

Appendices

Appendix 1: Definitions and sources of variables

Variables	Definitions	Sources
CO2 emissions	log of carbon emissions in kilotons	WDI (World Bank)
Financial development	Composite financial development index (depth, access and efficiency)	Findex database (IMF)
Remittances	Remittances as a percentage of GDP	WDI (World Bank)
Foreign aid	Net official development assistance (% of GDP)	WDI (World Bank)
Foreign investment	Foreign direct investment as a percentage of GDP	WDI (World Bank)
Trade openness	Imports and exports as a percentage of GDP	WDI (World Bank)
Renewable energy	Renewable energy consumption as a percentage of total final energy	WDI (World Bank)
Income	log of real gross domestic product growth per capita	WDI (World Bank)
Government effectiveness	“Government effectiveness (estimate): measures the quality of public services, the quality and degree of independence from political pressures of the civil service, the quality of policy formulation and implementation, and the credibility of governments’ commitments to such policies”	WGI (World Bank)
Mobile phone	Mobile phone subscriptions (per 100 people)	WDI (World Bank)
Population	Population growth (% of annual)	WDI (World Bank)

WDI: World Development Indicators. WGI: World Governance Indicators. IMF: International Monetary Fund.

Appendix 2: Summary Statistics

	Mean	S.D	Min	Max	Obs
CO2 emissions (log)	8.262	1.550	5.010	13.012	459
Financial development	0.165	0.117	0.042	0.648	459
Remittances	2.732	3.047	0.000	14.063	459
Foreign aid	6.778	6.127	-0.249	39.431	459
Foreign investment	4.639	6.516	-1.032	57.837	459
Trade openness	72.157	36.327	19.100	225.023	459
Renewable energy	63.475	27.326	0.709	95.354	459
Income (log)	3.914	0.953	-0.343	4.557	459
Government effectiveness	-0.526	0.607	-1.766	1.056	459
Mobile phones	58.202	44.346	0.000	184.298	459
Population	2.446	0.826	-2.628	4.629	459

SD: Standard Deviation. Min: Minimum. Max: Maximum.

Appendix 3: correlation matrix (uniform sample size: 459)

	CO2	F.D	Remi	ODA	FDI	Trade	Renergy	Income	Gov.E	Mobile	Pop
CO2	1.000										
F.D	0.450	1.000									
Remi	-0.216	-0.168	1.000								
ODA	-0.557	-0.461	0.188	1.000							
FDI	-0.167	-0.018	-0.059	0.033	1.000						
Trade	-0.266	0.315	-0.083	-0.248	0.495	1.000					
Renergy	-0.155	-0.770	0.005	0.430	-0.095	-0.598	1.000				
Income	-0.002	-0.669	0.085	0.346	-0.181	-0.683	0.785	1.000			
Gov.E	0.108	0.699	-0.170	-0.243	-0.022	0.344	-0.738	-0.640	1.000		
Mobile	0.242	0.503	-0.040	-0.485	0.105	0.387	-0.527	-0.482	0.361	1.000	
Pop	-0.040	-0.669	0.024	0.311	-0.036	-0.481	0.753	0.694	-0.616	-0.378	1.000

CO2: Carbon emissions. F.D: Financial Development. Remi: Remittances. ODA: Official Development Assistance. FDI: Foreign Direct Investment. Renergy: Renewable Energy. Income: GDP per capita. Gov.E: Government Effectiveness. Mobile: Mobile Phone Penetration. Pop: Population.

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