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RENEWABLE ENERGY CONSUMPTION, FINANCIAL INCLUSION AND ENVIRONMENTAL SUSTAINABILITY IN SUB-SAHARAN AFRICA

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Abstract

Purpose – This research enriches the existing literature on the importance of renewable energy by exploring how financial inclusion can moderate the impact of renewable energy consumption on environmental sustainability.

Design/methodology/approach – The focus is on 26 sub-Saharan African nations for the period 2004 to 2022, and the empirical evidence is based on interactive fixed effects and quantile regressions.

Findings – The following results were established. First, financial inclusion, measured by the number of users of automated teller machines (ATMs) and commercial bank branches, moderates renewable energy consumption to have an overall negative effect on carbon dioxide emissions. Second, overall financial inclusion moderates the consumption of renewable energy to generate an overall negative effect on carbon dioxide emissions in sub-Saharan African countries with medium and high pollution levels. Political implications are discussed.

Originality/value – The study complements the extant literature by examining how inclusive finance can be relevant in assessing how renewable energy affects the sustainability of the environment.

Keywords: renewable energy consumption; financial inclusion; environmental sustainability

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1.Introduction

Concerns surrounding renewable energy consumption and resource depletion remain relevant issues in scholarly and policy circles (Arabatzis et al., 2013; Azam et al., 2016; Tampakis et al., 2017; Kyriakopoulos et al., 2018; Zafeiriou et al., 2022; Tsopmo et al., 2024), especially as it pertains to managing the renewable energy sector to promote environmental sustainability (Deka et al., 2024; Makridou et al., 2024). The positioning of the study within the remit of extant literature on the subject is motivated by three fundamentals in the relevant scholarly and policy literature, particularly with regard to, among other things: (i) the increasing significance of renewable energy consumption in the achievement of some United Nations sustainable development goals (SDGs); (ii) the pertinent role of financial inclusion in the achievement of attendant SDGs and (iii) gaps in the relevant scholarship on the subject. The three motivational features are enlarged in the same time frame as they are highlighted in what follows.

First, concerning the relevance of the problem statement to sustainable development, it is worthwhile to note that the reduction of carbon dioxide (CO_2) emissions in order to promote environmental sustainability is fundamental to some United Nations SDGs, as well as some critical points of Agenda 2063 of the African Union (Atedhor, 2023; Kisira & Jack, 2024). It follows that the present study has pertinence both in an African-centric agenda as well as in the achievement of more comprehensive SDGs in term of reducing carbon emissions around the world. Some of the documented mechanisms established in the literature by which such CO_2 emissions can be mitigated are financial inclusion (Odhiambo, 2020) and renewable energy consumption (Qin et al., 2021). Although to the best of my/our knowledge, the corresponding literature interacting these mechanisms to assess their overall incidence on CO_2 emissions is scarce.

Second, there is a growing consensus on the extant policy and scholarly literature that financial inclusion is fundamental in promoting development outcomes (Odhiambo et al., 2023), especially as it pertains to outcomes that are connected to sustainable development as seen within the parameters of the current explanation (Odhiambo, 2020; Asongu & Vo, 2020). As clarified in Section 2.2 on theoretical underpinnings, financial inclusion is relevant in the process of adopting renewable energy with the ultimate goal of reducing CO_2 emissions in order to promote environmental sustainability. The positioning of the present study is also inspired by a gap in the available literature on environmental sustainability in Africa.

Third, with regard to the gap in the extant literature that the study aims to fill, as clarified in Section 2, the extant studies in the literature have not been concerned with the problem statement being considered in this study. Accordingly, the closest study in the extant literature to the present exposition is Kwakwa (2023), which has investigated the relevance of renewable energy consumption and institutional quality in mitigating CO_2 emissions in Africa. In other words, the study has focuses on how institutional quality moderates in the incidence of renewable energy consumption on CO_2 emissions in the continent. The empirical evidence is based on the Fully Modified Ordinary Least Squares and the model known as Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT). The distinguishing feature of the present exposition in the light of Kwakwa (2023) is self-evident not least, because the present study focuses on the role of financial inclusion on moderating the incidence of renewable energy consumption on CO_2 emissions in sub-Saharan Africa. Moreover, the methodologies are also distinct, not least because the present study uses fixed effects and quantile regressions. In essence, the fixed effects regressions are tailored such that both the unobserved heterogeneity and simultaneity dimensions of endogeneity are taken into account, especially as it pertains to, respectively, accounting for time and country fixed effects on the one hand and on the other, employing the lagged independent and control variables in order to account for the simultaneity dimension of endogeneity.

The following structure organizes the remaining research. The empirical literature, theoretical underpinnings, testable hypotheses and conceptual framework are engaged in Section 2, whereas Section 3 discusses the data and methodology. Findings from the empirical analysis are provided in Section 4. The last section or Section 5 concludes with implications, limitations and corresponding future research directions.

2.Empirical literature, theoretical underpinnings and hypotheses development

2.1 Empirical literature

2.1.1 Linkage between renewable energy and environmental sustainability

Bekele et al. (2024) examined the dynamic relationship between renewable energy usage and environmental sustainability in Sub-Saharan African countries using heterogeneous macro-panel data analysis over the period of 2000 to 2023. The study employed the Augmented Mean Group Estimator technique and Granger Causality test to analyze annual data in 30 sub-Saharan African countries. According to the study's findings, using renewable energy significantly reduces greenhouse gas emissions in sub-Saharan African nations, confirming economic theory that renewable energy positively influences environmental sustainability. Additionally, a two-way nexus between renewable energy consumption and greenhouse gas emissions was revealed from the Granger Causality test. The study recommended among others that governments in sub-Saharan African countries should create energy policies through subsidies and tax incentives to encourage renewable energy consumption, which should be prioritized to meet the increasing energy demands.

Qudrat-Ullah and Nevo (2021) studied the impact of renewable energy usage and environmental sustainability on economic growth in Africa. The Generalized Method of Moments (GMM) estimation technique was utilized in the study to estimate panel data covering thirty-seven African countries over the period of 2004 - 2018. Findings from the study revealed a positive relationship between renewable energy and economic growth in Africa both in the short and long run and further showed no existence of a significant relationship between renewable energy and economic growth. The shortcoming of this study is the limited availability of data which may not accurately capture all contributing factors of interest hence, leading to a biased result. The study however, recommended that sampled African governments should utilize policy instruments that can strengthen renewable energy consumption in order to achieve environmental sustainability.

Syamni et al. (2021) explored the relationship between renewable energy and sustainable development in Indonesia. Secondary data from the World Bank Development Indicators was used in the study. The Autoregressive Distributed Lag (ARDL) technique was employed to analyze the variables, and findings from the study revealed that renewable energy consumption both in the short and long-run has a positive effect on economic growth. Renewable energy was seen as a necessary requirement for economic growth compared to foreign direct investment. The study further concluded with a unique view point that the government must invest in alternative energy sources like solar to boost the economy. They also recommended that government authorities should invest in renewable energy as it is a necessity for economic growth.

Phong and Sarkodie (2020) examined the dynamic relationship between the usage of conventional and renewable energy, economic growth, and environmental quality with emphasis on emerging market and developing economies during the period 1990 to 2014. The authors employed a second-generational econometric technique and Westerlund panel cointegration test to investigate the variables' long-term relationship. This is after detecting that the variables were stationary at first difference and level series using the unit root test. The Adaptive Minimum Gradient (AMG), Conditional Covariance Estimator for Mixed Graphics (CCEMG), and Mean Group (MG) estimators were also employed to assess the long run effect between the variables. It was revealed from the result that renewable energy and conventional energy use, trade openness and capital formation, alongside government expenditure and CO_2 emissions significantly enhance Emerging Markets and Developing Economies (EMDE's) economic growth. The study recommended that EMDE's should prioritize and put into place sensible policies that can encourage green energy and economic restructuring in order to lower atmospheric CO_2 emissions.

2.1.2 The linkage between financial inclusion and environmental sustainability

Sadiq and Ali (2024) examined the digital financial inclusion (DFI) and environmental sustainability nexus in South Asian economies spanning from 2011 – 2021. The study utilized the GMM technique to analyze the data and Principal Component Analysis (PCA) method was also employed to develop the index. The results from the GMM analysis revealed that an increase in DFI (financial inclusion) will lead to a decrease in environmental sustainability, thereby (financial inclusion) depicting a significant positive relationship with CO_2 emissions. It also demonstrated that while the growing use of the internet promotes environmental sustainability, renewable energy consumption and population expansion have a negative influence on CO_2 emissions, whereas GDP growth and industrialization engendered no significant effect on CO_2 emissions. The authors succinctly recommended that the government should improve accessibility of mobile phones and internet services to enhance technological infrastructure.

Hussian et al. (2023) empirically investigated the relationship between financial inclusion and carbon emissions adopting the STIRPAT framework for 102 countries spanning from 2004 – 2020. The study employed PCA and the Panel Regression Analysis method for its analysis. The result from the panel analysis depicted an N-shaped relationship between financial inclusion and carbon emissions, implying that there is an existence of a nonlinear connection between carbon emissions and financial inclusion. The study concluded that this finding is strong in developing countries but weak in advanced countries and recommended that the government authorities should develop an inclusive financial policy that considers varying degrees of governance, regulations and income across nations.

Faheem, Nousheen and Farooq (2023) examined the part that financial inclusion plays in Pakistan's environmental sustainability. The study adopted the Autoregressive Distributed Lag (ARDL) Model and the result showed that financial inclusion and trade have a detrimental effect on emissions of carbon dioxide. This implies that financial inclusion and trade enhance the quality of the environment by lowering CO_2 emissions. In addition, the result also showed that foreign direct investment and GDP reduce environmental quality by enhancing the level of CO_2 outflow. The authors concluded that financial inclusion and trade must be enhanced to boost environmental quality. They further recommended that the government should protect investors by implementing rules and regulations that attract trade.

Odugbesan, Ike and Olowu (2020) assessed the causality between financial development, financial inclusion and sustainable development in 33 sub-Saharan African countries with emphasis on the mediating role of foreign direct investment in a panel of 33 sub-Saharan African economies spanning from 2004 – 2018. The authors employed the panel cointegration and panel granger causality tests methods. Findings from the study, the cointegration test particularly showed an existence of a long-run relationship among the variables. The panel estimation also showed a positive significant nexus between financial development and sustainable development and same positive relationship between FDI and sustainable development. Moreover, FDI serves as the mechanism between financial inclusion and sustainable development as the impact of financial inclusion moves through the channel of FDI and down to sustainable development. The study primarily recommended that policy makers should incentivize the flow of foreign direct investment into the economy's productive sectors in order to guarantee sustainable growth.

2.2 Theoretical underpinnings, hypotheses development and conceptual framework

2.2.1 Renewable energy and environmental sustainability

The link between energy renewal and environmental preservation is based on a theoretical foundation. It is important to emphasize that these theoretical currents address the issue of the relevance of energy renewal to reduce environmental damage and promote a healthy environment. The circular economy theory is the main theory that explains the link between energy renewal and environmental sustainability in the context of our research.

The circular economy theory encourages the reuse and recycling of resources in order to reduce waste and environmental issues. According to this theory, it is assumed that environmental impacts can be reduced by using renewable energy and green technologies, which could also promote economic growth. It is clear that the constant and significant increase in the consumption of renewable energy is effective in reducing the adverse consequences on the environment in terms of carbon dioxide emissions (Chen et al., 2022). However, the literature indicates that this alternative is generally feasible in industrialized nations as well as nations with more robust institutions. Indeed, it is crucial to consider the environmental consequences of renewable energy in order to reduce the harmful consequences and maximize the benefits for the environment (Jamil et al., 2022). Renewable energy has a much lower environmental impact compared to non-renewable energy. It lowers air pollution, greenhouse gas emissions, and toxic waste (Usman & Makhdum, 2021; Dogan et al., 2022; Raghutla et al., 2022), while non-renewable energies contribute to these environmental problems. Renewable energy is of great importance, suggesting that the consumption of renewable energy is the best solution to manage environmental problems (Ikram et al., 2021). According to Osman et al. (2023), renewable energy could account for 65% of the global electricity supply by 2030 and by 2050, it could reduce carbon emissions by 90% from the electricity sector, which would significantly reduce carbon emissions and contribute to climate change mitigation. Therefore, it is essential to promote clean renewable energy in order to avoid global warming caused by carbon dioxide produced by the use of non-renewable energy (Hall, 1991; Panwar et al., 2011).

2.2.2 Renewable energy, financial inclusion and environmental sustainability

The theoretical framework supporting the moderating of financial inclusion in the nexus between renewable energy and environmental sustainability within the remit of CO_2 emissions is consistent with the extant financial inclusion literature (Odhiambo, 2019; Asongu & Odhiambo, 2024). According to the attendant literature, two main theoretical positions can be used to motivate the pertinence of financial inclusion in sustainable development outcomes, namely: the intensive and extensive margin theoretical underpinnings. The first or intensive margin theory maintains that when extant customers of banks or financial institutions are provided with enhanced possibilities of increasing financial resources at their disposable, such financial resources are used to achieve many prospects which entail inclusive and sustainable development outcomes such as the funding of renewable energy sources in view of limiting their carbon footprint. It follows that when existing customers are provided with more financial resources by banks, these financial resources can be used to purchase energy channels that are designed to limit CO_2 emissions: the main objective of the present study.

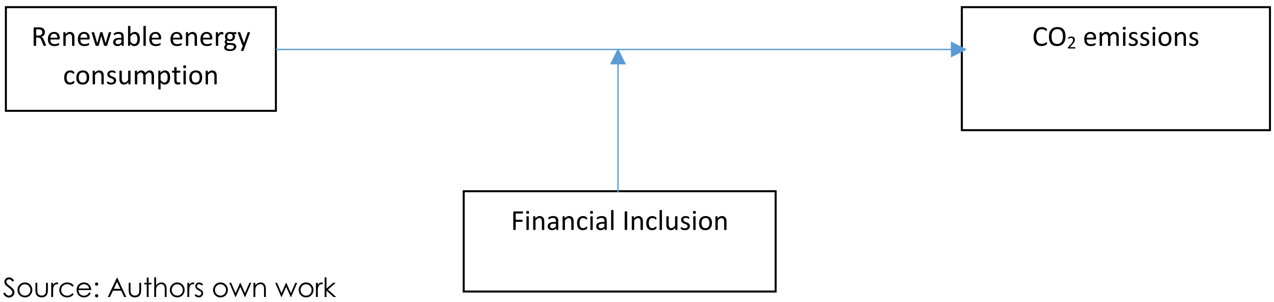
In the light of the above, the extensive margin of theoretical underpinnings follow the same logic on the linkages between renewable energy and CO_2 emissions, with the exception that, in this second strand, the corresponding additional financial resources are provided to new bank customers, especially those that did not previously own bank accounts in the attendant financial institutions. Building the theoretical underpinnings of the present exposition, which is logical and easy to follow, as well as the narratives in the previous section supporting the negative nexus between renewable energy consumption and CO_2 emission (Adams & Nsiah, 2019; Wang et al., 2021;), the following testable hypotheses can be objectively formulated:

Hypothesis 1: renewable energy consumption reduces CO_2 emissions

Hypothesis 2: financial inclusion complements renewable energy consumption to reduce CO_2 emissions.

In order to enhance readability and flow, the underlying testable hypotheses are captured in the conceptual framework that follows in Figure 1.

Figure 1: The role of financial inclusion on the relationship between renewable energy and CO_2 emissions



Source: Authors own work

In Figure 1, Hypothesis 1 is the horizontal nexus or arrow between renewable energy and CO_2 emissions. Conversely Hypothesis 2 is captured by the vertical arrow, which supports the position that financial inclusion complements renewable energy consumption to reduce CO_2 emissions. Whether the theoretical postulations and corresponding testable hypotheses withstand empirical scrutiny is an object of empirical scrutiny, which is the focus of the next section.

3.Data and methodology

3.Data

The study focuses on a panel of 26 sub-Saharan African countries for the period 2004 to 2022. The corresponding data is obtained from various sources, namely: Yale University, the Financial Access Survey of the International Monetary Fund, the World Development Indicators of the World Bank and Principal Component Analysis (PCA). These sources are clarified in Appendix 2 in relation to the corresponding variables. In line with the study's goal, the independent variable of interest or primary channel is the use of renewable energy, whereas the dependent variable is CO_2 emissions during the use of solid, liquid, gas, and gas flaring fuels (Chen et al., 2022 ; Dogan et al., 2022; Raghutla et al., 2022; Osman et al., 2023). The moderating variable is financial inclusion, which is appreciated from six main perspectives, namely: five financial inclusion dynamics and a six financial inclusion composite indicator obtained from PCA. The choice of more financial inclusion moderating variables in order to improve room for policy implications is in line with the body of existing research on financial inclusion. (Tchamyou et al., 2019; Ngono, 2021; Asongu et al., 2023, 2024).

Table 1 presents the principal component analysis (PCA) results for the financial inclusion (i.e. Findex) composite indicator. As shown in the table, about 72% of the variance contained in the first principal component (PC) is retained from the PCA to measure Findex. It is crucial to emphasize that the Kaiser criterion, which states that only components with eigenvalues larger than one should be kept, is followed for keeping the first principal component (PC) (Tchamyou, 2020). The five financial inclusion variables used for the financial inclusion indicator making-up the retained PC are: number of automated teller machines users (ATMS) subscribers per 100,000 adults (ATM2); number of commercial bank branches per 100, 000 adults (NCBB2); number of depositors with commercial banks per 1,000 adults (NDCB); outstanding deposits with commercial banks (% of GDP) (ODCB) and Outstanding loans from commercial banks (% of GDP) (OLACB).

In order to account for potential determinants of CO_2 emissions, six main control variables are considered, in accordance with the relevant CO_2 emissions literature (Ohlan, 2015; Sulaiman & Abdul-Rahim, 2018; Halkos & Polemis, 2017; Sabir et al., 2020; Demena & Afesorgbor, 2020; Achuo et al., 2022; Nousheen & Farooq, 2023; Mignamissi et al., 2024a, 2024b; Sadiq & Ali, 2024). These variables as defined in Appendix 2 are: Urbanization, industrial production, population, environmental policy, trade and government effectiveness. According to the underlying literature, urbanization, industrial production, population and trade should increase CO_2 emissions while environmental policy and government effectiveness should reflect the opposite effect. The list of countries is provided in Appendix 1 while the definitions and corresponding sources of the variables are disclosed in Appendix 2. Appendix 3 and Appendix 4 provide the summary statistics and correlation matrix respectively.

Table 1. Principal Component Analysis (PCA) for Composite Financial Inclusion

Principal Components	Component Matrix (Loadings)					Proportion	Cumulative Proportion	Eigen Value
	ATM2	NCBB2	NDCB	ODCB	OLACB			
First PC	0.472	0.424	0.472	0.441	0.424	0.719	0.719	3.598
Second PC	-0.307	-0.527	-0.207	0.500	0.579	0.165	0.885	0.825
Third PC	-0.273	0.685	-0.617	0.271	0.025	0.049	0.934	0.248
Fourth PC	0.558	-0.055	-0.495	-0.467	0.471	0.046	0.980	0.230
Five PC	-0.545	0.264	0.328	-0.514	0.512	0.019	1.000	0.098

PC. Principal Component. ATM2: Number of automated teller machines users (ATMS) subscribers per 100,000 adults. NCBB2: Number of commercial bank branches per 100, 000 adults. NDCB: Number of depositors with commercial banks per 1,000 adults. ODCB: Outstanding deposits with commercial banks (% of GDP). OLACB: Outstanding loans from commercial banks (% of GDP).
Source: Authors own work

3.2 Methodology

In accordance with the insights provided in the introduction, two main estimation approaches are adopted: on the one hand, the fixed effects regressions that are tailored to account for some dimensions of endogeneity and on the other, the quantile regressions approach that is designed to assesses the nexuses all along the outcome variable's conditional distribution or CO_2 emissions. In what follows, the corresponding estimation techniques are discussed in detail.

3.2.1 Fixed effects regressions

Our empirical methodology consists of employing a panel data analysis to examine to what extent renewable energy consumption in interaction with financial inclusion can reduce CO_2 emissions. Considering the literature's theoretical and empirical bases (Odhiambo, 2019; Chen et al., 2022; Asongu & Odhiambo, 2024; Bekele et al., 2024; Sadiq & Ali, 2024), and considering the rewards of interactive regressions for improved policy options (Ehigiamusoe & Samsurijan, 2021: Tchamyou et al., 2023), we specify Equation (1) as follows:

$$\boldsymbol{CO2_{i,t} = \gamma_1 RE_{i,t-1} + \gamma_2 FI_{i,t-1} + \gamma_3 (RE_{i,t-1} \times FI_{i,t-1}) + \phi Z_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t}} \quad (1)$$

Where the dependent variable $CO2$ is a measure of CO_2 emissions. The relevant explanatory variables are measurements of Renewable energy consumption (RE) and Financial Inclusion (FI), which consists of six main variables. The vector Z is a set of control variables including Urbanization, industrial production, population, environmental policy, trade and government effectiveness. The terms μ_i is the unobservable impact that is specific to each country, λ_t symbolize the imperceptible time effects that encapsulate the impact of macroeconomic shocks that could have an impact on all nations at once, and $\varepsilon_{i,t}$ are error terms. The country and time indicators are denoted by the subscripts i and t, respectively. Since this helps to lessen the possibility of reverse causation with the dependent variables, we lag the explanatory variables (Tchamyou et al., 2023).

3.2.2. Quantile regressions

The goal of this study is to investigate the relationships among CO_2 emissions, financial inclusion, and the use of renewable energy, taking into account the motivating factors mentioned in the introduction. The quantile regressions approach is therefore used in this study in light of the motivational insights offered to support the estimation technique because it allows an evaluation of the relationships between financial inclusion, renewable energy consumption, and CO_2 emissions by focusing on nations with low, intermediate, and high initial levels of CO_2 emissions (Asongu, 2024).

Given the foregoing, this study aims to investigate connections across the conditional distribution of CO_2 emissions. The accepted quantile regressions approach is therefore chosen in light of the accompanying motivating factors, not least because it allows the research to achieve the intended goal. The selected estimation technique is orientated so that the resulting results emphasize low, high, and intermediate levels of the outcome variable or CO_2 emissions in light of the corresponding recent quantile regression literature (Billger & Goel, 2009; Tchamyou & Asongu, 2017).

It is also crucial to make clear that, unlike the OLS approach, which is primarily predicated on the assumption that the corresponding error terms are normally distributed, the quantile regressions approach does not always require that the error terms be normally distributed. This is due in part to the fact that estimated parameters are taken into account at different points along the conditional distribution of CO_2 emissions. As a result, the description of the chosen methodology is consistent with the literature on quantile regressions (Koenker & Bassett, 1978; Keonker & Hallock, 2001; Asongu et al., 2023).

Considering the approach to estimation, the θ th quantile estimator of CO_2 emissions is derived by addressing the optimization concern in Equation (2), that is disclosed in the absence of subscripts for the aim of simplicity in presentation.

$$\min_{\beta \in R^k} \left[\sum_{i \in \{i: y_i \geq x_i' \beta\}} \theta \left| y_i - x_i' \beta \right| + \sum_{i \in \{i: y_i < x_i' \beta\}} (1-\theta) \left| y_i - x_i' \beta \right| \right], \qquad (2)$$

where $\theta \in (0,1)$. Comparative to the OLS approach, which is essentially tailored to reduce the total sum of residuals that are squared, the quantile regression framework operates such that the absolute deviations of attendant quantiles are maximised. For example, for the underlying technique, a multitude of quantiles such as the 10th quantile or the 90th (respectively, corresponding to θ =0.10 or 0.90) are minimised by weighing the residuals approximately. The attendant conditional quantile of CO_2 emissions or y_i given x_i is:

$$Q_y(\theta / x_i) = x_{i'}\beta_\theta \quad (3)$$

where with respect to each θ th quantile that is examined, parameters that are consistent with unique slopes are modelled. The corresponding formulation is parallel to $E(y/x) = x_{i'}\beta$ when the OLS slope is taken into account such that, parameters are largely assessed at the average of the conditional distribution of CO_2 emissions.

For the model in Eq. (2), the dependent variable y_i is the CO_2 emissions indicator while x_i contains a constant term, renewable energy consumption, financial inclusion (i.e., one of the six proxies), urbanization, industrial production, population, environmental policy, trade and government effectiveness.

4.Empirical results

The empirical results are provided in this section in Tables 2-5. While Tables 2-4 provide findings related to the fixed effects regressions, Table 5 discloses the corresponding findings related to the quantile regressions. It is relevant to note that, as clarified in the motivation of the present study, the fixed effects regressions are also tailored to account for two dimensions of endogeneity, namely: (i) the unobserved heterogeneity within the remit of country and time fixed effects and (ii) the simultaneity or reverse causality dimension, by regressing the contemporary outcome variables on lagged independent and control variables. In so doing, the estimation exercise is oriented such that non-contemporary financial inclusion and renewable energy consumption affect contemporary CO_2 emissions. This is more logical because decisions to reduce CO_2 emissions that are followed by concrete actions in terms of adopting renewable energies with the help of financial access, are more likely to engender the corresponding consequences in terms of reducing CO_2 emissions only the following year.

It is also relevant to note that from the quantile regressions, the responsiveness of CO_2 emissions to interactions between renewable energy consumptions and financial inclusion are contingent on initial levels of CO_2 emissions, such that the responsiveness varies throughout the conditional distribution of CO_2 emissions. It follows that the analytical approach is also oriented to inform policy makers on the essence to avoid blanket policies. This is essentially because if the responsiveness of CO_2 emissions to interactions between financial inclusion and renewable energy consumption is contingent on initial levels of CO_2 emissions, policy makers will be poised to formulate policy measures, contingent on initial levels of CO_2 emissions. It follows that the corresponding policy orientations in the light of the problem statement can be tailored differently across countries with various initial levels of CO_2 emissions, especially as it pertains to above- and below-median levels of CO_2 emissions.

In order to avail room for policy implications, the study is consistent with extant interactive regressions literature (Asongu & Odhiambo, 2020, 2021) by computing the net effect of renewable energy consumption. The computation of net effect is motivated on the premise that while Hypothesis 1 is overwhelming validated, in order to asses Hypothesis 2 the corresponding role of financial inclusion in the effect of renewable energy consumption on CO_2 emissions should be computed. It is relevant to recall that Hypothesis 1 is the position that renewable energy consumption reduces CO_2 emissions while Hypothesis 2 is the stance that financial inclusion complements renewable energy consumption to reduce CO_2 emissions.

Table 2 provides the baseline results while Table 3 takes into account the simultaneity dimension of the estimation by regressing the contemporary outcome variable on non-contemporary independent and control variables. In Table 4, three year non-overlapping intervals are used in order to account for business cycle disturbances while still accounting for the simultaneity dimension of endogeneity. The following consistent findings are apparent in Tables 2-4. First, financial inclusion, measured by the number of users of automated teller machines (ATMs) and commercial bank branches, moderates renewable energy consumption to have an overall negative effect on carbon dioxide emissions. Second, according to the narrative in the data section, the majority of the significant control variables exhibit the expected signals.

Table 2. Renewable energy consumption, financial inclusion and environmental sustainability (baseline results)

	Dependent variable : Environmental sustainability (CO2)					
VARIABLES	ATM2	NCBB2	NBCD	ODCB	OLACB	FINDEX
Automatic Tellers Machines (ATM2)	**-0.798****					
	(0.315)					
Renerg X ATM2	**0.183****					
	(0.0792)					
Commercial Banks (NCBB2)		**-0.960*****				
		(0.309)				
Renerg x NCBB2		**0.222****				
		(0.0798)				
Bank Institutions (NBCD)			0.577			
			(0.624)			
Renerg x NBCD			-0.164			
			(0.145)			
Deposits in banks (ODCB)				-0.420		
				(0.509)		
Renerg x ODCB				0.0753		
				(0.125)		
Loans in banks (OLACB)					-0.172	
					(0.294)	
Renerg x OLACB					0.0486	
					(0.0860)	
Findex						0.350
						(0.527)
Renerg x Findex						-0.113
						(0.137)
Renewable Energy (Renerg)	**-1.248*****	**-1.403*****	**-1.352*****	**-1.198*****	**-1.178*****	**-1.572****
	(0.396)	**(0.386)**	**(0.406)**	**(0.386)**	**(0.373)**	**(0.559)**
Urbanization	-0.146	0.0316	0.739**	-0.0798	-0.106	0.493
	(0.459)	(0.360)	(0.345)	(0.380)	(0.384)	(0.378)
Industrial Production	0.134	0.150	0.0241	0.183	0.241*	-0.113
	(0.152)	(0.119)	(0.0963)	(0.130)	(0.130)	(0.118)
Population	0.999	**1.833*****	**3.533*****	**2.179****	**2.189*****	**3.709*****
	(0.975)	**(0.632)**	**(0.321)**	**(0.757)**	**(0.727)**	**(0.857)**
Environment Policy	-0.00941	-0.00406	0.00520	-0.00280	-0.00295	0.00373
	(0.00958)	(0.00684)	(0.00720)	(0.00838)	(0.00792)	(0.00999)
Trade	0.172	**0.213****	**0.108****	**0.241****	**0.209****	**0.115****
	(0.111)	**(0.0824)**	**(0.0448)**	**(0.100)**	**(0.0978)**	**(0.0520)**
Government Effectiveness	**0.127***	0.0438	0.0369	0.0756	0.0530	0.0873
	(0.0654)	(0.0716)	(0.0919)	(0.0737)	(0.0770)	(0.0944)
Net Effect of Renewable Energy	-1.140	-1.275	na	na	na	na
Constant	-2.979	-17.21	**-47.03*****	**-23.60***	**-23.87***	**-47.68*****

	(17.75)	(11.44)	**(5.061)**	**(13.29)**	**(12.86)**	**(13.78)**
Countries/Observations	26/242	26/323	26/262	26/318	26/318	26/179
R-squared Within	0.461	0.533	0.608	0.480	0.471	0.493
F-statistic/P-value	21.81/0.000	10.30/0.000	21.63/0.000	6.64/0.000	4.82/0.002	3.49/0.016

Note. Robust standard errors in parentheses are clustered at the country. Absorbed fixed effects (period country) are included. *** p<0.01, ** p<0.05, * p<0.1. na: not applicable given that at least one estimated coefficient that is indispensable for the computation of net effects does not reflect significance. nsa: not specifically applicable because the threshold found does not lie between the minimum and maximum of the moderating variable (financial inclusion). The dimensions of financial inclusion and the composite indicator of financial inclusion are normalized between 0 and 1.
Source: Authors own work

Table 3. Renewable energy consumption, financial inclusion and environmental sustainability (with the first lags of explanatory variables)

	Dependent variable : Environmental sustainability (CO2)					
VARIABLES	ATM2	NCBB2	NDCB	ODCB	OLACB	FINDEX
L.(Automatic Tellers Machines) (L.ATM2)	**-0.957****					
	(0.346)					
L.Renerg X L.ATM2	**0.220****					
	(0.0871)					
L.(Commercial Banks) (L.NCBB2)		**-0.851****				
		(0.303)				
L.Renerg x L.NCBB2		**0.217****				
		(0.0805)				
L.(Bank Institutions) (L.NBCD)			0.555			
			(0.560)			
L.Renerg x L.NBCD			-0.131			
			(0.136)			
L.(Deposits in banks) (L.ODCB)				-0.601		
				(0.521)		
L.Renerg x L.ODCB				0.128		
				(0.131)		
L.(Loans in banks) (L.OLACB)					-0.0865	
					(0.262)	
L.Renerg x L.OLACB					0.0313	
					(0.0821)	
L.Findex						0.656
						(0.424)
L.Renerg x L.Findex						-0.166
						(0.110)
L.(Renewable Energy) (L.Renerg)	**-0.989****	**-1.104*****	**-1.007****	**-0.993****	**-0.920****	**-1.277****
	(0.348)	**(0.349)**	**(0.368)**	**(0.356)**	**(0.349)**	**(0.473)**
L.Urbanization	-0.0143	0.0346	0.872*	-0.0811	-0.0636	0.555
	(0.402)	(0.384)	(0.435)	(0.377)	(0.388)	(0.385)
L.(Industrial Production)	0.0865	0.186	0.00694	0.251*	0.305**	-0.0490
	(0.180)	(0.142)	(0.147)	(0.122)	(0.125)	(0.138)
L.Population	0.982	**1.743****	**3.332*****	**2.338*****	**2.409*****	**4.540*****
	(1.058)	**(0.679)**	**(0.318)**	**(0.731)**	**(0.756)**	**(0.872)**
L.(Environment Policy)	-0.00709	-0.000762	0.00505	0.00155	0.00119	0.00865
	(0.00778)	(0.00682)	(0.00721)	(0.00745)	(0.00722)	(0.00698)

L.Trade	**0.262****	**0.244****	**0.124***	**0.284****	**0.257****	**0.239*****
	(0.123)	**(0.0950)**	**(0.0677)**	**(0.108)**	**(0.101)**	**(0.0522)**
L.(Government Effectiveness)	0.0657	0.0284	0.0326	0.0556	0.0424	0.0408
	(0.0852)	(0.0881)	(0.115)	(0.0891)	(0.0895)	(0.115)
Net Effect of Renewable Energy	-0.858	-0.979	na	na	na	na
Constant	-4.523	-17.35	**-45.67*****	**-27.57****	**-29.22****	**-63.56*****
	(19.13)	(12.28)	**(4.948)**	**(12.76)**	**(13.20)**	**(14.25)**
Countries/Observations	26/223	26/304	26/246	26/299	26/299	26/163
R-squared Within	0.430	0.456	0.5070	0.428	0.422	0.541
F-statistic/P-value	62.51/0.000	12.38/0.000	32.49/0.000	4.81/0.002	4.71/0.002	4.50/0.005

Note. Robust standard errors in parentheses are clustered at the country. Absorbed fixed effects (period country) are included. *** p<0.01, ** p<0.05, * p<0.1. L. denotes the first lag. na: not applicable given that at least one estimated coefficient that is indispensable for the computation of net effects does not reflect significance. nsa: not specifically applicable because the threshold found does not lie between the minimum and maximum of the moderating variable (financial inclusion). The dimensions of financial inclusion and the composite indicator of financial inclusion are normalized between 0 and 1.
Source: Authors own work

Table 4. Renewable energy consumption, financial inclusion and environmental sustainability, control for business cycle (using three-year averages data)

	Dependent variable : Environmental sustainability (CO2)					
VARIABLES	ATM2	NCBB2	NDCB	ODCB	OLACB	FINDEX
L.(Automatic Tellers Machines) (L.ATM2)	**-0.957****					
	(0.346)					
L.Renerg X L.ATM2	**0.220****					
	(0.0871)					
L.(Commercial Banks) (L.NCBB2)		**-0.851****				
		(0.303)				
L.Renerg x L.NCBB2		**0.217****				
		(0.0805)				
L.(Bank Institutions) (L.NBCD)			0.555			
			(0.560)			
L.Renerg x L.NBCD			-0.131			
			(0.136)			
L.(Deposits in banks) (L.ODCB)				-0.601		
				(0.521)		
L.Renerg x L.ODCB				0.128		
				(0.131)		
L.(Loans in banks) (L.OLACB)					-0.0865	
					(0.262)	
L.Renerg x L.OLACB					0.0313	
					(0.0821)	
L.Findex						0.656
						(0.424)
L.Renerg x L.Findex						-0.166

						(0.110)
L.(Renewable Energy) (L.Renerg)	**-0.989****	**-1.104*****	**-1.007****	**-0.993****	**-0.920****	**-1.277****
	(0.348)	**(0.349)**	**(0.368)**	**(0.356)**	**(0.349)**	**(0.473)**
L.Urbanization	-0.0143	0.0346	**0.872***	-0.0811	-0.0636	0.555
	(0.402)	(0.384)	**(0.435)**	(0.377)	(0.388)	(0.385)
L.(Industrial Production)	0.0865	0.186	0.00694	**0.251***	**0.305****	-0.0490
	(0.180)	(0.142)	(0.147)	**(0.122)**	**(0.125)**	(0.138)
L.Population	0.982	**1.743****	**3.332*****	**2.338*****	**2.409*****	**4.540*****
	(1.058)	**(0.679)**	**(0.318)**	**(0.731)**	**(0.756)**	**(0.872)**
L.(Environment Policy)	-0.00709	-0.000762	0.00505	0.00155	0.00119	0.00865
	(0.00778)	(0.00682)	(0.00721)	(0.00745)	(0.00722)	(0.00698)
L.Trade	**0.262****	**0.244****	**0.124***	**0.284****	**0.257****	**0.239*****
	(0.123)	**(0.0950)**	**(0.0677)**	**(0.108)**	**(0.101)**	**(0.0522)**
L.(Government Effectiveness)	0.0657	0.0284	0.0326	0.0556	0.0424	0.0408
	(0.0852)	(0.0881)	(0.115)	(0.0891)	(0.0895)	(0.115)
Net Effect of Renewable Energy	-0.83	-0.73	na	na	na	na
Constant	-4.523	-17.35	**-45.67*****	**-27.57****	**-29.22****	**-63.56*****
	(19.13)	(12.28)	**(4.948)**	**(12.76)**	**(13.20)**	**(14.25)**
Countries/Observations	223	304	246	299	299	163
Within R-squared	0.430	0.456	0.507	0.429	0.422	0.541
F-statistic/P-value	62.51/0.000	12.38/0.000	32.49/0.000	4.81/0.000	4.71/0.002	4.50/0.005

Note. Robust standard errors in parentheses are clustered at the country. Absorbed fixed effects (period country) are included. *** p<0.01, ** p<0.05, * p<0.1. L. denotes the first lag. na: not applicable given that at least one estimated coefficient that is indispensable for the computation of net effects does not reflect significance. nsa: not specifically applicable because the threshold found does not lie between the minimum and maximum of the moderating variable (financial inclusion). The dimensions of financial inclusion and the composite indicator of financial inclusion are normalized between 0 and 1.
Source: Authors own work

In order to account for initial levels of CO_2 emissions, the Findex composite indicator is employed in the quantile regressions disclosed in Table 5. It is apparent from the findings that overall financial inclusion moderates the consumption of renewable energy to generate an overall negative effect on carbon dioxide emissions in sub-Saharan African countries with medium and high pollution levels. It follows that the responsiveness of CO_2 emissions to interactions between renewable consumption and the financial inclusion index is contingent on initial levels of CO_2 emissions and thus from a policy framework, have to be customized accordingly for nations with varying starting CO_2 emissions levels.

Table 5. Renewable energy consumption, financial inclusion and environmental sustainability (quantile regression)

	Dependent variable : Environmental sustainability (CO2)					
VARIABLES	OLS	Q.10	Q.25	Q.50	Q.75	Q.90
L.Findex	**-3.945*****	-2.311	-1.857	**-3.878*****	**-4.764****	**-6.333*****

	(0.810)	(2.067)	(2.082)	**(1.350)**	**(1.939)**	**(1.083)**
L.Renerg x L.Findex	**0.963*** **	0.558	0.450	**0.971*** **	**1.123** **	**1.438*** **
	(0.203)	(0.492)	(0.495)	**(0.321)**	**(0.461)**	**(0.258)**
L.Renerg	**-2.363*** **	**-1.891*** **	**-2.042*** **	**-2.435*** **	**-2.877*** **	**-2.972*** **
	(0.165)	**(0.327)**	**(0.329)**	**(0.214)**	**(0.307)**	**(0.171)**
L.Urbanization	0.00364	-0.125	0.0645	-0.209	0.215	**0.232** **
	(0.104)	(0.215)	(0.217)	(0.140)	(0.202)	**(0.113)**
L.(Industrial Production)	0.000903	-0.258	0.277	**0.416*** **	0.167	-0.0175
	(0.171)	(0.223)	(0.225)	**(0.146)**	(0.209)	(0.117)
L.Population	**1.105*** **	**1.019*** **	**1.006*** **	**0.915*** **	**1.177*** **	**1.264*** **
	(0.0631)	**(0.102)**	**(0.103)**	**(0.0669)**	**(0.0961)**	**(0.0536)**
L.(Environment Policy)	**0.0732*** **	**0.0774*** **	**0.0435*** **	**0.0477*** **	**0.0730*** **	**0.0906*** **
	(0.00786)	**(0.0108)**	**(0.0109)**	**(0.00708)**	**(0.0102)**	**(0.00568)**
L.Trade	**0.564*** **	**0.463***	**0.674** **	0.265	0.352	**0.599*** **
	(0.169)	**(0.267)**	**(0.269)**	(0.174)	(0.250)	**(0.140)**
L.(Government Effectiveness)	**-0.248*** **	0.0607	-0.118	**-0.396*** **	**-0.600*** **	**-0.580*** **
	(0.0910)	(0.118)	(0.118)	**(0.0768)**	**(0.110)**	**(0.0616)**
Net Effect of Renewable Energy	-1.894	na	na	-1.959	-2.326	-2.267
Constant	**-5.236*** **	-4.481	**-5.463***	-0.363	**-4.610***	**-6.506*** **
	(1.706)	(2.878)	**(2.898)**	(1.879)	**(2.699)**	**(1.507)**
R^2/Pseudo R^2	0.882	0.757	0.711	0.695	0.685	0.680
Fisher	**237.52*** **					
Observations	163	163	163	163	163	163

Note. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. OLS : Ordinary Least Squares. Pseudo R^2 for quantile regression and R^2 for OLS. Lower quantiles (e.g., Q 0.1) signify countries where environmental sustainability is least. L. denotes the first lag. na: not applicable given that at least one estimated coefficient that is indispensable for the computation of net effects does not reflect significance. nsa: not specifically applicable because the threshold found does not lie between the minimum and maximum of the moderating variable (financial inclusion).

Source: Authors own work

Before concluding, it is necessary to quickly analyze the known findings in light of the body of existing research on the topic. Accordingly, the findings are consistent with Bekele et al. (2024) on the negative effect of renewable energy consumption and CO_2 emissions in Sub-Saharan African countries, though the Augmented Mean Group Estimator technique and Granger Causality test were employed in the study for the period 2000 to 2023. Sadiq and Ali (2024) on the negative incidence of renewable energy consumption on CO_2 emissions in South Asian countries from 2011-202l using the GMM estimation approach. Hussian et al. (2023) on the close connection between environmental sustainability and financial inclusion in emerging nations for the period 2004-2020 using a STIRPAT framework. Faheem et al. (2023) who established that financial inclusion promote environmental quality within the remit of reducing CO_2 emission in Pakistan using an ARDL approach. Odugbesan et al. (2020) who have established a strong nexus between financial development and sustainable development in sub-Saharan over the period 2004-2008.

5.Conclusion, implications and future research directions

This research has enriched the existing literature on the relevance of renewable energy by exploring how financial inclusion can moderate the impact of renewable energy consumption on environmental sustainability. The analysis covers 26 sub-Saharan African countries for the period 2004 to 2022, and the empirical evidence is based on interactive fixed effects and quantile regressions. The following results were established. First, financial inclusion, measured by the number of users of ATMs and commercial bank branches, moderates renewable energy consumption to have an overall negative effect on carbon dioxide emissions. Second, overall financial inclusion moderates the consumption of renewable energy to generate an overall negative effect on carbon dioxide emissions in sub-Saharan African countries with medium and high pollution. Theoretical and policy implications are discussed in what follows.

In terms of theoretical implications, the findings are consistent with the circular economy theory, especially as it pertains to the reduction of CO_2 emissions by means of renewable energy in view of promoting environmental sustainability. It follows that within the contemporary remit of the sampled countries, contingent on the estimation technique, adopted periodicity and corresponding variables employed, the theoretical underpinnings on the relevance of renewable energy in reducing CO_2 emissions withstand empirical scrutiny, especially with understood from the perspective of the validation of Hypothesis 1.

On the practical front, in terms of policy implications, four perspectives are worth considering: (i) the negative effect of renewable energy consumption on CO_2 emissions; (ii) the contingency financial inclusion dynamics in moderating renewable energy to reduce CO_2 emissions; (iii) financial inclusion being a necessary but not a sufficient moderator of renewable energy consumption for the mitigation of CO_2 emissions and (iv) the validity of the moderating relevance being constrained by initial levels of CO_2 emissions. First, the perspective that renewable energy consumption mitigates CO2 emissions has a direct policy implication that is self-evident. It implies that policymakers of the nations included in the sample should develop and execute relevant measures that can be put in place to encourage the consumption of renewable in households, firms and government structures with the ultimate aim of reducing the carbon footprint of corresponding countries.

A step in this direction will be to encourage and subsidize the use of technologies that are focused on the consumption of renewable energy in view of promoting carbon neutrality, environmental sustainability and net-zero emission. Some of the steps in the direction of promoting renewable energy consumption, could be inter alia: (i) encouraging ethanol blending, which is worthwhile to governments ability to mitigate high reliance and the import of gas and oil; (ii) promote innovative market reforms that are tailored to provide incentives the uptake and deployment of renewable energy; (iii) adopting of efficient energy mix and grid flexibility frameworks, which are essential in non-contemporary planning on how to address seasonal mismatches with respect to shortages in energy and how to provide law-carbon solution in view of maintaining household and economic activities.

Second, the contingency financial inclusion dynamics in moderating renewable energy to reduce CO_2 emissions, as established in this study shows that not all financial inclusion policy variables can effectively moderate renewable energy consumption in order to ultimately reduce CO_2 emissions. It follows that based on the considered financial inclusion dynamics in the study, those measured by the number of users of ATMs and commercial bank branches, are the most effective policy instruments. Hence, the use of financial inclusion policy variables should be based on empirical scrutiny because not all are effective.

Third, beyond the policy consideration of financial inclusion, complementary policies should also be taken into account, especially from the understanding that financial inclusion being a necessary but not a sufficient moderator of renewable energy consumption for the mitigation of CO_2 emissions. Accordingly, given the positive interactive effects, it is apparent that complementary policies are worthwhile for the purpose of promoting environmental sustainability by means of renewable energy consumption, contingent on financial inclusion. Some of the attendant complementary policies have been highlighted while discussing the first policy implication this section, inter alia, encouraging ethanol blending, promoting innovative market reforms and adopting of efficient energy mix and grid flexibility frameworks.

Fourth, the fact that when the financial inclusion index is employed across the conditional distribution of CO_2 emissions, different findings emerge, is relevant in the perspective that the validity of the moderating relevance is constrained by initial levels of CO_2 emissions. Hence, financial inclusion policies that entail the five financial inclusion dynamics considered in this study under the composite measurement of a financial inclusion index, in order to be effective, should be contingent on initial levels of CO_2 emissions and thus tailored differently across countries with various CO_2 emissions levels.

Future research is clearly possible given the results of this study, particularly when it comes to evaluating additional policy factors and mechanisms that can be used to reduce CO_2 emissions and support environmental sustainability in Africa and other developing nations. In addition, determining whether the established findings hold up to empirical examination in economies with greater technological sophistication will give scholars and policymakers pertinent information about the connections between advancing environmental sustainability through financial inclusion and the use of renewable energy.

Appendices

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Appendix 1. List of countries (26) of the study

Angola, Benin, Botswana, Burkina Faso, Cabo Verde, Chad, Cote d'Ivoire, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Malawi, Mali, Mauritius, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, South Africa, Togo, Uganda, Zambia and Zimbabwe

Source. Authors' construction

Appendix 2. Definitions and sources variables

Variables	Signs	Definitions	Sources
CO_2 emissions (kt)(log)	CO_2	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.	WDI (World Bank)
	ATM2	Number of automated teller machines users (ATMS) subscribers per 100,000 adults.	
	NCBB2	Number of commercial bank branches per 100, 000 adults.	
Financial inclusion	NDCB	Number of depositors with commercial banks per 1,000 adults.	FAS (FMI)
	ODCB	Outstanding deposits with commercial banks (% of GDP).	
	OLACB	Outstanding loans from commercial banks (% of GDP).	
	FINDEX	A financial inclusion indicator that encompasses all indicators.	PCA
Renewable Energy (log)	lrenerg	Renewable energy consumption is the share of renewables energy in total final energy consumption.	WDI (World Bank)
Industrial Production (log)	lindus_gdp	Manufacturing, value added (% of GDP). Manufacturing refers to industries belonging to ISIC divisions 15-37. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Note: For VAB countries, gross value added at factor cost is used as the denominator.	WDI (World Bank)
Urbanization (log)	lurban	Urban population below 5m is the percentage of the total population, living in areas where the elevation is 5 meters or less.	WDI (World Bank)

Population (log)	lpop	Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship. The values shown are midyear estimates.	WDI (World Bank)
Environment Policy	epi	Environmental Performance Index	Yale University
Trade (log)	ltrad	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product.	WDI (World Bank)
Government Effectiveness	gef	Government Effectiveness captures perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. Estimate gives the country's score on the aggregate indicator, in units of a standard normal distribution, i.e. ranging from approximately -2.5 to 2.5.	WDI (World Bank)

WDI: World Bank Development Indicators of the World Bank. FAS: Financial Access Survey of the FMI.

Source: Authors own work

Appendix 3. Summary Statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
CO2 (log)	442	8.243	1.613	5.325	13.013
ATM2	408	0.588	0.34	0	1
NCBB2	491	0.574	0.337	0	1
NDCB	389	0.459	0.322	0	1
ODCB	468	0.465	0.312	0	1
OLACB	467	0.486	0.315	0	1
FINDEX	304	0.49	0.31	0	1
Renewable Energy (log)	453	3.868	0.985	-0.342	4.554
Industrial Production (log)	494	3.12	0.363	1.609	4.125
Urbanization (log)	418	3.51	0.423	2.506	4.512
Population (log)	494	16.047	1.556	11.32	19.202
Environment Policy	494	38.539	6.109	26.673	61.606
Trade (log)	435	4.204	0.402	3.305	5.463
Government Effectiveness	494	-0.562	0.657	-1.807	1.15

The dimensions of financial inclusion and the composite indicator of financial inclusion are normalized between 0 and 1.

Std.Dev: Standard Deviation.

Source: Authors own work

Appendix 4. Correlation matrix

	Dependent variable	Financial inclusion dynamics						Renewable energy	Control variables						VIF	1/VIF
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)		
(1) CO23	1.000															
(2) ATM2	0.158	1.000													2.92	0.342
(3) NCBB2	0.018	0.442	1.000												2.28	0.438
(4) NDCB	0.107	0.536	0.503	1.000											2.30	0.435
(5) ODCB	-0.065	0.327	0.426	0.543	1.000										3.00	0.332
(6) OLACB	0.106	0.293	0.544	0.390	0.644	1.000									3.12	0.320
(7) FINDEX	0.136	0.740	0.400	0.605	0.585	0.511	1.000								4.49	0.222
(8) Renewable Energy	-0.446	-0.054	-0.008	-0.189	0.022	0.185	0.037	1.000							3.82	0.261
(9) Industrial Production	0.450	0.169	-0.078	-0.040	-0.267	-0.153	0.089	-0.170	1.000						2.61	0.382
(10) Urbanization	-0.697	-0.053	0.128	0.055	0.029	0.060	0.033	0.379	-0.244	1.000					3.08	0.324
(11) Population	0.554	0.112	0.136	-0.011	0.109	0.220	0.137	0.308	0.271	-0.498	1.000				4.55	0.219
(12) Environment Policy	0.183	0.069	-0.203	0.065	-0.163	0.072	0.074	-0.142	0.058	-0.015	-0.308	1.000			1.62	0.616
(13) Trade	0.259	0.067	-0.061	0.073	-0.089	-0.088	0.030	-0.547	0.488	-0.149	-0.355	0.222	1.000		2.96	0.338
(14) Government Effectiveness	0.254	0.063	0.002	0.065	-0.055	-0.246	0.103	-0.570	0.047	-0.321	-0.012	-0.043	0.081	1.000	2.20	0.454
Mean															**3.00**	

Source: Authors own work

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