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Financial Inclusion and Environmental Sustainability in Emerging and Developing Countries: Do control of corruption and trade openness matter?

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ABSTRACT

This study investigates the impact of financial inclusion on environmental sustainability in 178 emerging and developing countries from 1996 to 2022. Employing a composite index derived through Principal Component Analysis (PCA) as a measure of financial inclusion and covering four aspects (access, depth, efficiency, stability), our analysis reveals negative outcomes. The findings indicate that enhancing financial inclusion is associated with a notable increase in CO2 per capita emissions as well as in Total Greenhouse Gas emissions. We demonstrate that controlling corruption improves environmental quality, yet this measure alone is insufficient to fully mitigate the impact of financial inclusion, as indicated by our moderation analysis. The same analysis, however, shows that fostering globalization through trade openness is an efficient tool to alleviate the positive effect of financial inclusion on the quality of the environment. The study employs various policies targeting the control of development levels, energy consumption, natural resource utilization, industry, and urban population dynamics to contextualize the influence of financial inclusion on environmental sustainability. Through econometric methods and a comprehensive examination of the specified time frame, our results provide insights into the complex interplay between financial inclusion and environmental outcomes in diverse socio-economic contexts. The research contributes to the discourse on sustainable development by highlighting the potential of certain factors as a catalyst for environmental improvement. Understanding these dynamics is crucial for policymakers, as it underlines the trade-off between integrating inclusive financial strategies and achieving environmentally sustainable development trajectories in emerging and developing nations. Moreover, shedding light on the underlying mechanisms, such as trade-offs, fills a significant gap in the literature.

KEYWORDS

Financial inclusion; Environmental sustainability; PCA; Panel; Moderation analysis

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1. Introduction

In the pursuit of global sustainability, we explore the pivotal role of financial inclusion in fostering environmental sustainability across a panel of 178 emerging and developing countries in the spirit of Qin et al. (2021), Wang et al. (2022), Amin et al. (2022), Ozturk et Allah (2022), Ozili (2023), Hussain et al. (2023), Ahmad and Satrovic (2023), etc. Recognizing the interconnected nature of economic empowerment and ecological resilience, our focus on this specific cohort stems from the realization that these nations often face unique challenges at the nexus of economic development and environmental conservation. The motivation behind our regional selection lies in the critical need to address these challenges and catalyze positive change where it is most impactful. An innovative aspect of our research lies in the construction of a comprehensive composite index of financial inclusion, comprising 34 indicators and utilizing the Principal Component Analysis (PCA) over the period 1996-2022. This groundbreaking approach aims to provide a nuanced understanding of the relationship between financial inclusion and environmental sustainability, offering a novel perspective on how inclusive financial systems can drive positive ecological outcomes in developing countries.

Developing economies actively pursue strategies to bolster financial inclusion. As highlighted by Morgan and Pontines (2014), these nations recognize the pivotal role they play in fostering overall economic growth and stability (Hanning and Jansen, 2010; Triki and Faye, 2015; Ozili, 2018; Xun et al., 2020; Yaung and Zhang, 2020; Ahmad et al., 2021; Liu et al., 2021a; Liu et al., 2021b; Li et al., 2021; Khera et al., 2021; Sun and Tang, 2022). Dev (2006) defines financial inclusion as making affordable banking services accessible to disadvantaged and low-income groups (Demirgüç-Kunt and Klapper, 2012). This encompasses credit, savings, insurance, and formal financial system services for payments and remittances, with a focus on those traditionally excluded (Arun and Kamath, 2015). Accounting for socioeconomic and infrastructure factors matters when the question comes to analyzing financial inclusion within a country (Sarma and Pais, 2011). Zins and Weilll (2016) argue that income and education levels are the most influencing determinants of financial inclusion, while population density necessarily leads to financial inclusion in Africa as claimed by Allen et al. (2014).[1] Importantly, access to financial services helps mitigate environmental issues (Chaudhry et al., 2022).

The ability to access finance has changed significantly in recent years and all over the world. While traditional touchpoints such as Automated Teller Machines (ATMs) and bank branches are on the decline, non-traditional platforms such as retail agents and mobile money agents are on the rise. The proliferation of digital access points for financial services has inevitably led to an increase in their usage, as measured by the increase in the number and volume of digital financial transactions. For example, in Africa, the epicenter of mobile money, the value of such transactions increased from 26% to 35% of GDP from 2021 to 2022.

However, in Europe and the Western Hemisphere, mobile and Internet banking have become a priority, with online banking transactions per 1,000 adults increasing by more than 20 percent in 2022 alone (Figure 1). We cannot talk about digital without referring to technology, which provides innovative solutions tailored to the expected uses. Its extremely rapid evolution requires the maintenance of technical know-how and the ability to work with an ecosystem in a secure way (Ediagbonya and Tioluwani ,2023).

Financial inclusion is multipronged and includes insurance and capital markets in addition to the banks. Although there is agreement on the magnitude of financial inclusion, there is still no clear understanding of what financial inclusion is and how it is measured. Although it is widely accepted that financial inclusion is multidimensional, it is debatable which dimensions are included and what value is given to each when defining financial inclusion (Kebede et al., 2021).

[1] For a succinct literature review on financial inclusion, see Gálvez-Sánchez et al. (2021).

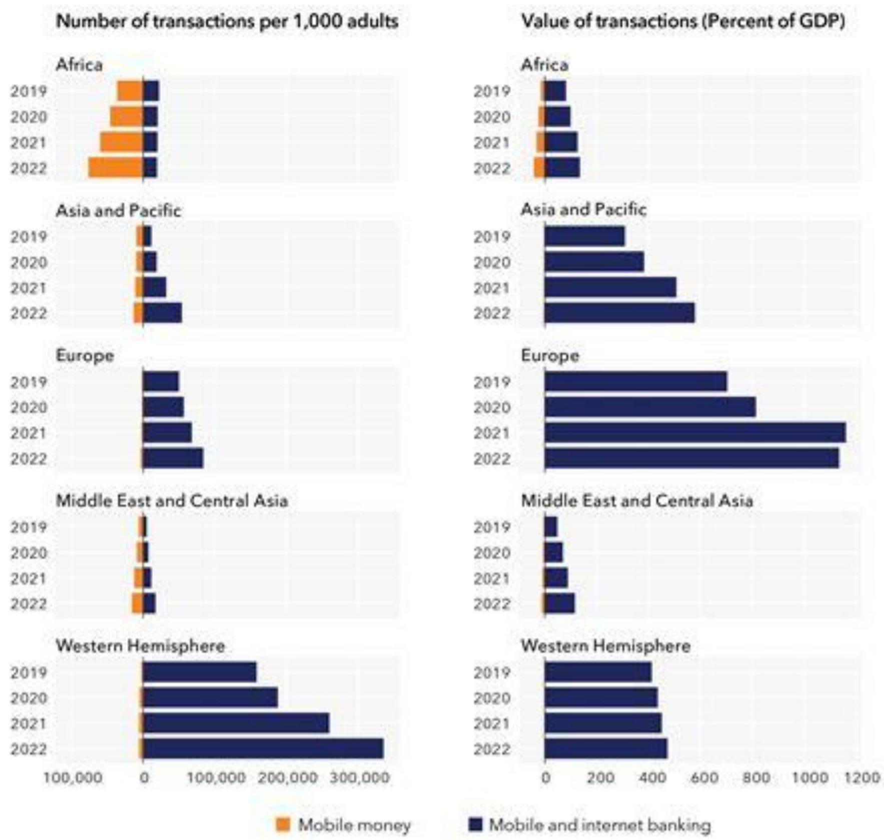

Figure 1. Expansion of usage of digital financial services.
Source: Financial Access Survey and IMF staff calculations.

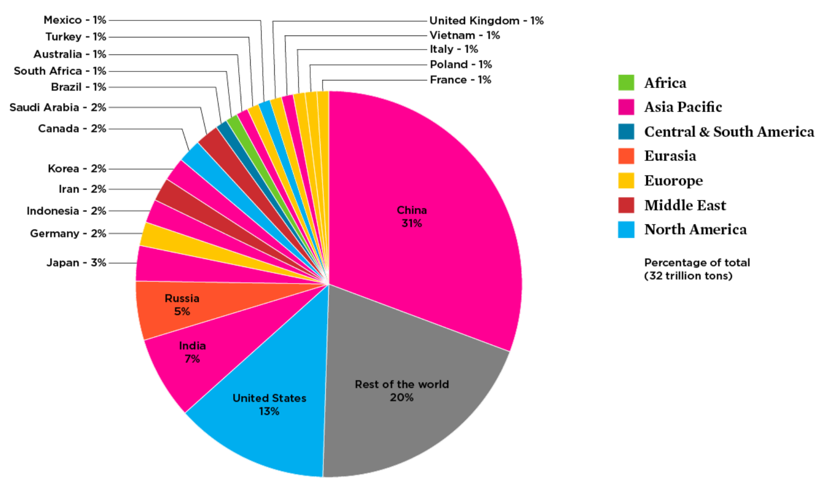

Figure 2. Top annual CO2 emitting countries, 2020 (from fossil fuels).
Source: IEA, ATLAS of Energy.

The question of linking environmental quality to financial inclusion is very recent and requires further attention, especially when we deal with emerging and developing economies. Our research is motivated by the notable environmental challenges experienced by the countries under consideration (Du et al., 2022). Furthermore, we observe significant disparities in outcomes concerning the impact of financial inclusion, among other documented factors, on environmental sustainability, motivating us to further empirical investigation using fresh data. Figure 2 shows that emerging and developing countries are the largest emitters of CO_2 per capita, making them again a reasonable target to fight against environmental degradation.

This paper aims to construct a comprehensive financial inclusion index for emerging and developing economies using PCA. The paper explores the impact of corruption and trade openness on the effectiveness of channeling financial inclusion to environmental sustainability. This is regarded as another important aspect of the study. We exemplify the existence of such a moderating effect in the case of trade openness.

The remainder of this paper is organized as follows. Section 2 reviews studies related to the quality of the environment and financial inclusion, especially in emerging and developing countries. Section 3 presents the data and methodology. In Section 4, we expose and discuss the results. Section 5 concludes the study and offers useful practical implications.

2. Literature review

Examining the impact of financial inclusion in emerging and developing countries constitutes a crucial and increasingly significant area of scholarly investigation, given its profound implications for economic development and societal advancement (Dev, 2006; Hannig and Jansen, 2010). It is further argued that financial inclusion supports Sustainable and Development Goals (SDGs) through Fintech (Arner et al, 2020) and it is effective to pursue energy management programmes (Dai et al., 2021). Brahmi et al. (2023) contended that financial inclusion presents a panacea for the transition to a decarbonized world. When accoupled with a well-supervised environment, it is an endeavor of growth in the short run.

Despite the expanding body of literature on financial inclusion, there exists a noteworthy void in the specific exploration of its consequences within the context of emerging and developing economies (Hussain et al., 2023). This research gap emphasizes the necessity of delving into this realm to enhance the informative basis for policy formulation and to foster inclusive growth (see Brahmi et al., 2023; Hashemizadeh et al., 2023). Prior research on financial inclusion within these regions, or specific locales, has predominantly concentrated on digital financial inclusion (e.g., Lee et al., 2022; Ozturk and Ullah, 2022; Ozili, 2023; Khan et al., 2023a; Khan et al., 2023b; Zhang et al., 2024). The outcomes revealed a dual impact of financial inclusion on environmental quality. Shi et al. (2022) posited that digital financial inclusion along with environmental regulation, can mitigate environmental pollution in Chinese provinces. Examining the context of the COVID-19 pandemic, Zheng et al. (2023) investigated the favourable effects of digital financial inclusion in curtailing carbon emissions. Also, Zhao et al. (2021) advocated for digital financial inclusion as a deterrent to CO_2 emissions per capita in China. Shabir (2022), focusing on Asia Pacific countries, championed financial inclusion as a driver of environmental sustainability. The beneficial effect of financial inclusion on CO_2 emissions is further depicted in studies of Shahbaz et al. (2022), Ababio et al. (2023), and Ogede and Tiamiyu (2023). Using separate indicators of financial inclusion such as ATMs, financial institution branches, and deposit accounts, Tariq et al. (2022) found a mixed effect of financial inclusion on environmental sustainability in emerging Asian countries. Conversely, Zhao et al. (2022) established a deleterious effect of financial inclusion on environmental sustainability in 48 developing countries, albeit with a limited focus on specific facets such as the number of ATMs and deposit accounts with commercial banks. Amin et al. (2022) aligned with Zhao et al. (2022) and asserted a positive impact of financial inclusion on CO_2 emissions in South Asian countries. Saqib et al. (2023) made use of the financial development index to portray financial inclusion and noted a decrease in ecological footprint in emerging and developing countries. The benefit is further complemented by alleviating the damaging effect of renewable energy.

Another strand of literature argues against financial inclusion for environmental sustainability. This includes Dou and Li (2022), Adeneye et al. (2023), and Singh et al. (2023). According to Dou and Li (2022), coping with a green environment comes with higher financial inclusion and energy efficiency in the case of BRICS countries. Adeneye et al. (2023) noted that digital financial inclusion leads to higher carbon emissions in African countries. similarly, Singh et al. (2023) found that financial inclusion engenders environmental degradation. Musah (2022) observed a deterioration in Ghana's environmental quality with increasing financial inclusion. Jingpeng et al. (2023) depicted a similar effect in South Asian countries but advanced nations are not excluded (see Liu et al., 2023). Growing evidence established a nonlinear effect of financial inclusion on emissions of CO2 or the absence of such an effect. Tanveer et al. (2023) mapped the response of Pakistan's environment to upward levels of financial inclusion and unveiled an asymmetric impact. Notably, an individual analysis by Barut et al. (2023) focusing on five fragile countries, has led to the rejection of a significant effect of financial inclusion on environmental quality. Empirical evidence of asymmetric impact is highlighted again in the work of Rehman et al. (2023). The authors noted that the impact of financial inclusion depends on the income levels of a country and that the effect is mediated through industrialization.[2]

Based on the above literature, we posit our first hypothesis as follows:

H1: Financial inclusion has a positive (negative) impact on environmental sustainability.

Parallel to the effect of financial inclusion, researchers sought the impact of governance including control of corruption on the quality of the environment. Corruption has serious consequences for the environment, and certain sectors are particularly vulnerable in this respect. Corruption occurs at all levels, from embezzlement in the implementation of environmental programmes to high corruption in granting licenses for exploiting natural resources to the payment of bribes to public officials. It can also be used to circumvent environmental or social protection measures. When corruption leads to the loss of resources and habitats and the destruction of ecosystems on which billions of people around the world depend, both people and the environment suffer (Zhong et al., 2023).

Emerging and developing countries are characterized by weak levels of institutional quality (Nkengfack et al., 2020; Koyamondja, 2023), making them a reasonable target. For example, Islam et al. (2023) showed a downward pattern of per capita CO2 if both institutional quality and financial inclusion are enhanced in Bangladesh. Tian and li (2023) consolidated these observations for G-20 nations using the CS-ARDL model.

Trade openness and globalization are also a premise for environmental sustainability. The general idea is that trade openness leads to an increase in economic activity and, consequently, more intense energy use. All other things being equal, the fact that economic activity and energy use take place on a larger scale will lead to higher levels of CO2 emissions. However, the effect will depend on the sectors in which a country has a comparative advantage. The effect on composition will lead to lower CO2 emissions if expanding sectors are less energy-intensive than sectors in recession. It is therefore difficult to predict in advance whether this effect will lead to an increase or decrease in CO2 emissions. For instance, Mulungula and Imubona (2022), Vu et al. (2023), and Tsimisaraka et al. (2023) cheered the role of globalization and trade openness in reducing environmental degradation while Tian and Li (2022), Lin and Wu (2022), and Gao et al. (2024) observed an adverse effect of globalization on the environmental health. Questioning transparent governments is of utmost importance when connecting environmental challenges to both financial inclusion and trade openness (Chien et al., 2023). Information and communication technologies (ICTs) make it possible to set up effective surveillance systems and facilitate the circulation of information (Waller-Hunter, 2002).

If financial inclusion deteriorates environmental performance, one should investigate mechanisms to mitigate the devastating impact. A possible way is to ensure a sustainable financial industry through increasing trade openness and foreign direct investments (Qamruzzaman, 2023) or through controlled corruption (Kumar et al., 2021; Tabash et al., 2023). We thus postulate our second and third hypotheses as follows on the grounds of a negative financial inclusion

[2] For a comprehensive review of papers, see Brahmi et al. (2023).

effect in the case of our sample.

H_2: Trade openness reduces the impact of financial inclusion on CO2 emissions.

H_3: control of corruption reduces the impact of financial inclusion on CO2 emissions.

Beyond the disparities in findings, the majority of prior studies primarily utilize CO2 emissions per capita as an indicator of environmental degradation. In our pursuit of robust findings, we augment our analysis by employing Total Greenhouse Gas emissions alongside carbon emissions. Importantly, we use a multidimensional index of financial inclusion covering four aspects (access, depth, efficiency, and stability). Thus, we go beyond digital financial inclusion (Khera et al., 2022) or the use of financial development (e.g., Zaidi et al., 2019; Nasir et al., 2019; Guo et al., 2019; Khan et al., 2019; Raheem et al., 2020; Wang et al., 2020; Shoaib et al., 2020; Shahbaz et al., 2020; Faheem et al., 2023, etc.), both of which are criticized. Furthermore, we aim to explain the mechanisms that lie behind the financial inclusion-environmental sustainability relationship. Particularly, we discuss the roles of control of corruption and trade openness as potential moderators. This methodological refinement seeks to provide a more comprehensive understanding of the relationship between financial inclusion and environmental health in emerging and developing countries.

3. Material and method

3.1. Measuring financial inclusion and controls

Secondary data are collected for 178 emerging and developing countries from the World Development Indicators (WDI) and Global Financial Development Database (GFDD) of the World Bank depending on their availability (see Table 1).[3] The time coverage is 1996-2022. The panel is unbalanced. Before exploring the dynamic linkage between financial inclusion and the quality of the environment, we need to establish a measurement for the former. Earlier studies have focused on singular indicators to measure financial inclusion (e.g., Honohan, 2008; Beck et al., 2009). However, such a consideration can be misleading (see Sarma, 2008; Sarma, 2012; Sarma, 2016). We acknowledge further efforts and progress in constructing more inclusive indicators (see Chakravarty and Pal, 2013; Amidžic et al., 2014; Cámara and Tuesta, 2014; Beck, 2016; Sethy, 2016; Ambarkhane et al., 2016; Mialou et al., 2017; Wang and Guan, 2017; Yorulmaz, 2018; Nguyen, 2020; Sha'ban et al., 2021; Park and Mercado, 2021, Tram et al., 2023, etc.). The proposed indices are generally based on Factor Analysis or axiomatic approaches. The variable of interest -financial inclusion- is constructed through the Principal Components Analysis (PCA) using four methods of normalization. According to Mazziotta and Pareto (2017, p. 166): "*Another motivation for the normalization is the fact that some indicators may be positively correlated with the phenomenon to be measured (positive polarity), whereas others may be negatively correlated with it (negative polarity).*" A total of 34 indicators are used based on Amin et al. (2021). In building our index, we follow three main steps. First, we examine both the supply side (access) and demand side (usage) of financial inclusion. Next, we improve the standard measure by adding efficiency and stability considerations in the second stage. The final step involves combining these refined measures to create the ultimate index. This approach ensures a thorough evaluation of financial inclusion, considering access, usage, efficiency, and stability for a more comprehensive assessment. Since indicators present different units and scales, we need to normalize them before the creation of the final index. There are four ways to do so. The Z-score standardization consists of subtracting the mean of each indicator and dividing by the standard deviation. However, the sample size and remedy related to additional data points should be warranted. The Min-Max method rescales variables by taking the minimum value aside and dividing by the difference between the maximum value to the minimum one. The weakness of this method is the necessity to fix the issue of new data points.

[3] For the list of countries, see: https://www.accessibilityassociation.org/s/emerging-and-developing-economies

The Softmax normalization technique proceeds in the same vein as the Z-score method but uses the exponential function (Le et al., 2019). The Sigmoid method is a nonlinear transformation of variables to a [0,1] range and it is suitable for a binary classification.

Table 1. Variables and definition**.**

Notation	Issue	Indicator Name	Source	Expected sign
Dependent variable				
logco2	Environmental sustainability	CO2 emissions (metric tons per capita)	WDI	
Controls				
loggdppp	Economic growth	Gross Domestic Product (GDP) per capita, Purchasing Power Parity PPP (constant 2017 international $)	WDI	+/-
logtrade	Economic integration	Trade (% of GDP)	WDI	+/-
logfdi	Economic integration	Foreign direct investment, net inflows (% of GDP)	WDI	+/-
lognatruaresource	Resource	Total natural resources rents (% of GDP)	WDI	+/-
logurban	Population	Urban population (% of total population)	WDI	+
logenergy	Energy use	The energy intensity level of primary energy (MJ/$2011 PPP GDP)	WDI	+
logindustry	Industry	Industry (including construction), value added (% of GDP)	WDI	+
Variable of interest				
logfi_zee	Financial inclusion	Financial inclusion composite index using PCA and Z-score method	Calculus	+/-
logfi_mmx	Financial inclusion	Financial inclusion composite index using PCA and Min-Max method	Calculus	+/-
logfi_softmax	Financial inclusion	Financial inclusion composite index using PCA and Softmax method	Calculus	+/-
logfi_sigmoid	Financial inclusion	Financial inclusion composite index using PCA and Sigmoid method	Calculus	+/-
Indicators for financial inclusion				
bankbranch1	Financial access	Bank branches per 100,000 adults	GFDD	
atm1	Financial access	Automated Teller Machines (ATMs) per 100,000 adults	GFDD	
pcredit1	Financial depth	Private credit by deposit money banks and other financial institutions to GDP (%)	GFDD	
deposit1	Financial depth	Deposit money banks' assets to GDP (%)	GFDD	
depositd1	Financial depth	Deposit money bank assets to deposit money bank assets and central bank assets (%)	GFDD	
liquid1	Financial depth	Liquid liabilities to GDP (%)	GFDD	
mutual1	Financial depth	Mutual fund assets to GDP (%)	GFDD	
cbanka1	Financial depth	Central bank assets to GDP (%)	GFDD	
financed1	Financial depth	Financial system deposits to GDP (%)	GFDD	
lifeins1	Financial depth	Life insurance premium volume to GDP (%)	GFDD	

nonlifeins1	Financial depth	Nonlife insurance premium volume to GDP (%)	GFDD
ins1	Financial depth	Insurance company assets to GDP (%)	GFDD
pcreditd1	Financial depth	Private credit by deposit money banks to GDP (%)	GFDD
pensiona1	Financial depth	Pension fund assets to GDP (%)	GFDD
dcredit1	Financial depth	Domestic credit to private sector (% of GDP)	GFDD
bnetmargin1	Financial efficiency	Bank net interest margin (%)	GFDD
blending1	Financial efficiency	Bank lending-deposit spread	GFDD
bnonint1	Financial efficiency	Bank noninterest income to total income (%)	GFDD
bankover1	Financial efficiency	Bank overhead costs to total assets (%)	GFDD
bankreturna1	Financial efficiency	Bank return on assets (%, after tax)	GFDD
bankreturne1	Financial efficiency	Bank return on equity (%, after tax)	GFDD
bankcost1	Financial efficiency	Bank cost-to-income ratio (%)	GFDD
bankreturnaa1	Financial efficiency	Bank return on assets (%, before tax)	GFDD
bankreturnee1	Financial efficiency	Bank return on equity (%, before tax)	GFDD
creditgov1	Financial efficiency	Credit to government and state-owned enterprises to GDP (%)	GFDD
stockturn1	Financial efficiency	Stock market turnover ratio (%)	GFDD
bzscore1	Financial stability	Bank Z-score	GFDD
bnonper1	Financial stability	Bank nonperforming loans to gross loans (%)	GFDD
bcapitala1	Financial stability	Bank capital to total assets (%)	GFDD
bcreditd1	Financial stability	Bank credit to bank deposits (%)	GFDD
bregulatory1	Financial stability	Bank regulatory capital to risk-weighted assets (%)	GFDD
liquida1	Financial stability	Liquid assets to deposits and short-term funding (%)	GFDD
provision1	Financial stability	Provisions to nonperforming loans (%)	GFDD
stockvol1	Financial stability	Stock price volatility	GFDD

The final components are selected so they explain more than 90% of the overall variance. When averaging all composite indices by year, the four methods give rise to the same values of financial inclusion whose evolution is traced in Figure 3. A negative noteworthy spike was observed in 2008, indicating that the usage of financial services was highly hit by the Global Financial Crisis. It is widely recognized that episodes of shocks and uncertainty induce distrust in banks and financial institutions, explaining why some persons do not hold formal accounts (Demirgüc-Kunt and Klapper, 2012). Overall, the index records an upward trend across all countries during the period of investigation. The validity of PCA is checked through the test of sphericity of Bartlett which and the values of Kaiser-Meyer-Olkin (KMO) measure. The p-values associated with the Bartlett test are lower than 1% of the significance level and KMO is high for all four normalization methods (see Table A.1 in Appendix). The set of controls is chosen among those that are well documented in the literature and have a potential influence on the quality of the environment. The latter is measured by emissions of CO2 per capita.

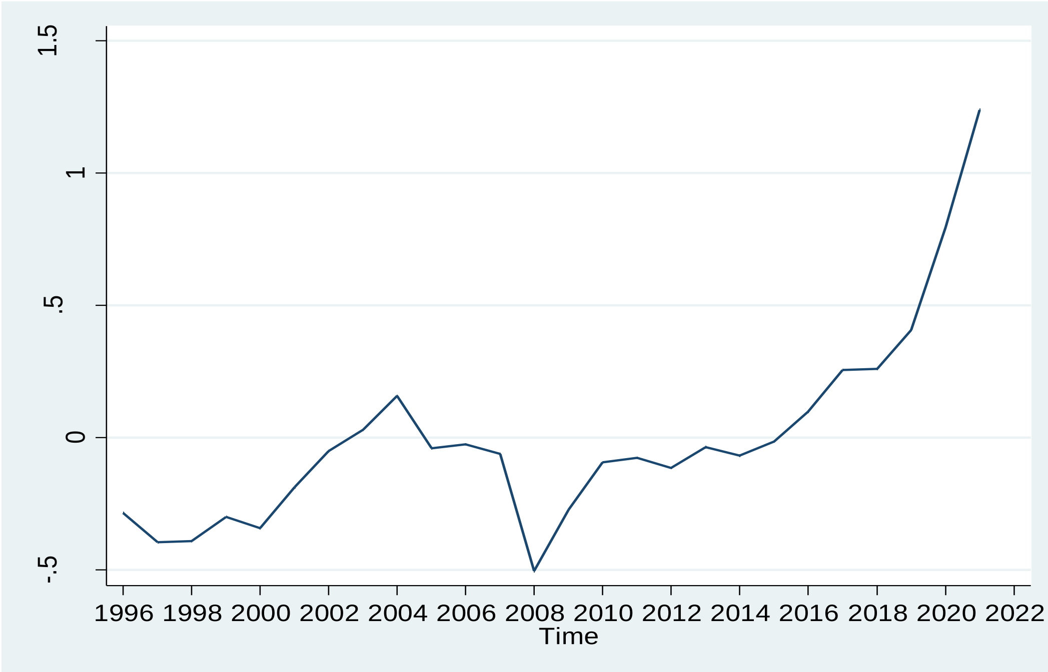

Figure 3. Evolution of the financial inclusion (calculated by PCA and averaged over all countries).

3.2 Econometric strategy

We employ an analytical model based on Dietz and Rosa (1997) who suggest the "Stochastic Impacts by Regression on Population, Affluence, and Technology" (STIRPAT) (Equation 1):

$$I_{it} = \alpha_{it} {P_{it}}^{\beta_1} {A_{it}}^{\beta_2} {T_{it}}^{\beta_3} \tag{1}$$

with I represents the environmental effects, P is population, A stands for Affluence, and T denotes technology.
The logarithm transformation is a static panel regression given by the following equation 2:

$$LOGY_{it} = \alpha_{it} + \theta LOGFI_{it} + \beta' LOGX_{it} + \varepsilon_{it} \tag{2}$$

where LOGY is the dependent variable and stands for environmental sustainability, LOGFI is the financial inclusion index and X is a series of controls for a country i at time t. Since we evidence the presence of a cross-sectional dependence (see Pesaran, 2004; Pesaran, 2015; Fan et al., 2015; Pesaran, 2021), we provide final estimates using Driscoll and Kraay's (1998) standard errors. The Driscoll and Kraay's estimator offers advantages in addressing spatial correlation and heteroscedasticity concerns in econometric models, providing more robust standard errors and reducing bias in parameter estimates compared to the standard Pooled Ordinary Least Squares (OLS) or Within estimators. There are three estimation techniques when proceeding to Driscoll and Kraay's estimation: Ordinary least Squares (OLS), Fixed effects (FE), and Random effects (RE). We apply the procedure of Hoechle (2007) which allows for choosing between FE and RE. The p-values at the bottom of Table 4 are below 1% of the significance level, indicating that the FE outperforms the RE.[4]

[4] We have tested for possible cointegration among variables, but the results indicate that no cointegration exists between the variables. Thus, panel techniques such as Cross-Section Autoregressive Distributed Lag (CS-ARDL are not applicable in our case.

4. Results and discussion

4.1. Preliminary analysis

Summary statistics of all variables are displayed in Table 2. The descriptive statistics provided in the table offer insights into various economic and demographic indicators across a sample of countries. For instance, in the context of CO2 emissions, the mean value is 0.217 with a standard deviation of 1.558, indicating substantial variability in emissions across nations. Similarly, GDP per capita, trade openness, and foreign direct investment exhibit relatively low means (1.080, 1.105, and 1.075, respectively), suggesting a concentration around the lower end of the scale. Urban population, with a mean of 8.875, shows a relatively narrow range, while energy use has a mean of 4.281 and a negative skewness, indicating a potential asymmetry in the distribution with more observations below the mean. The industry variable has a mean of 1.439 but with a higher standard deviation, indicating greater variability. The financial inclusion measures, whether using Z-score, Min-Max, Softmax, or Sigmoid normalization method, demonstrate diverse patterns, with different means, standard deviations, and skewness values, suggesting varying degrees of inclusivity across the sampled countries. The kurtosis values for most variables are within a reasonable range, indicating the general shape of the distributions.

Table 2. Descriptive statistics.

	N° observations	Mean	S.D.	Min	Max	Skewness	Kurtosis
CO2 emissions	3735	0.217	1.558	-6.943	3.864	-0.338	2.563
GDP per capita	2784	1.080	0.526	0.000	2.545	-0.169	2.646
Trade openness	2784	1.105	0.534	0.000	2.483	-0.265	2.532
Foreign direct investment	2784	1.075	0.514	0.000	2.402	-0.274	2.588
Natural resource rents	2784	1.075	0.514	0.000	2.402	-0.274	2.588
Urban population	3923	8.875	1.071	6.219	11.625	0.021	2.484
Energy use	3686	4.281	0.537	-3.616	6.761	-1.703	21.392
Industry	3994	1.439	1.004	0.000	7.858	1.631	9.692
Financial inclusion (Z-score)	3718	0.834	2.288	-9.802	4.473	-1.241	4.475
Financial inclusion (Min-Max)	4576	3.856	0.512	2.003	4.605	-0.640	2.761
Financial inclusion (Softmax)	1469	1.524	0.574	-0.916	3.335	0.235	3.994
Financial inclusion (Sigmoid)	2892	3.174	0.494	1.177	4.462	-0.455	3.748

The pairwise correlation matrix provides valuable insights into the relationships between different variables (see Table 3). Notably, the correlation coefficient between logco2 (carbon dioxide emissions) and loggdppp (GDP per capita) is strongly positive at 0.914, indicating a robust positive association between economic prosperity and carbon emissions. Conversely, financial inclusion composite measures, logfi_zee, logfi_mmx, logfi_softmax, and logfi_sigmoid, exhibit negative correlations with emissions of CO2 (logco2), suggesting that as financial inclusion improves, carbon emissions tend to decrease. Additionally, GDP per capita (loggdppp) shows positive correlations with logtrade (0.350) and logfdi (0.193), signifying those wealthier nations tend to engage more in international trade and attract higher foreign direct investment. Furthermore, urban population (logurban) demonstrates a positive correlation with loggdppp (0.662), indicating a link between urbanization and economic development. The correlation coefficients also reveal some noteworthy negative associations, such as the negative correlations between CO2 per capita (logco2) and natural resources (lognaturalresource) (-0.090) and industry use (logindustry) (-0.010), suggesting that as carbon emissions increase, there is a tendency for lower dependence on natural resources and industrial activities. These correlations provide valuable but insufficient insights into the interplay between various economic and environmental variables. Thus, we move on to panel regressions to identify the causality and the magnitude of the coefficients associated with the variable of interest as well as the controls.

Table 3. Pairwise correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) logco2	1.000											
(2) logfi_zee	-0.061***	1.000										
(3) logfi_mmx	-0.009	0.945***	1.000									
(4)logfi_softmax	-0.053**	0.982***	0.951***	1.000								
(5) logfi_sigmoid	-0.053**	0.982***	0.951***	1.000***	1.000							
(6) loggdppp	0.914***	-0.070***	-0.029	-0.063***	-0.063***	1.000						
(7) logtrade	0.350***	-0.082***	-0.058***	-0.075***	-0.075***	0.332***	1.000					
(8) logfdi	0.193***	-0.042**	-0.032	-0.047**	-0.047**	0.205***	0.405***	1.000				
(9) lognaturalresource	-0.090***	-0.013	-0.042**	-0.018	-0.018	-0.173***	-0.134***	-0.104***	1.000			
(10) logurban	0.662***	-0.120***	-0.081***	-0.110***	-0.110***	0.679***	0.206***	0.104***	0.021	1.000		
(11) logenergyuse	-0.017	0.032	0.033	0.034	0.034	-0.005	-0.006	0.014	0.032	-0.029	1.000	
(12) logindustry	-0.010	0.021	0.030	0.020	0.020	-0.009	-0.044**	-0.011	-0.044**	-0.002	0.233***	1.000

*Notes: *** p<0.01, ** p<0.05, * p<0.1.*

4.2. The baseline results

Table 4 exposes the output of the panel regressions. We posit the existence of individual effects (FE) to address heterogeneity among emerging and developing countries. Data exhibit problems of serial correlation, heteroskedasticity, and cross-sectional dependence, supporting the suitability of the Driscoll and Kraay's estimator. Our causality analysis, conducted through panel regressions, yields consistent findings about the financial inclusion-environmental sustainability nexus. Panel regressions, more informative than correlation analyses, elucidate causality direction, sign, and coefficient magnitudes. Across all variations of Equation (2), financial inclusion emerges as an exacerbating factor for CO2 emissions per capita, indicating that improved access, institutional depth, efficiency, and stability collectively alleviate environmental sustainability in these countries. Control variables reveal that an increase in foreign direct investment (logfdi) adversely impacts environmental health, causing a 0.036% to 0.039% rise in CO2 emissions (logco2). Conversely, greater trade openness (logtrade) diminishes CO2 emissions by 0.067 to 0.070%, while the urban population proportion and income per capita (logdppp) exhibit positive impacts on carbon emissions, contradicting the Environmental Kuznets Curve Hypothesis for emerging and developing economies. Additionally, higher natural resource rents (lognaturalresource) correspond to elevated carbon emissions, while the variable industry (logindustry) lacks significant influence on environmental quality.

Upon substituting the dependent variable with Total Greenhouse Gas emissions (logtge), it becomes evident that financial inclusion contributes to environmental degradation for all PCA composite indices (see Table 4). An increase of 1% in financial inclusion leads to a 0.34% increase in Total Greenhouse gas emissions. Notably, the impact of other control variables manifests consistently with the same sign, indicating a coherent pattern, and exhibits similar statistical significance, emphasizing the need for a subtle understanding of the dynamics between economic factors and ecological consequences. The development of any country should not be at the expense of environmental health

(Bhatnagar and Pathak, 2021; Tufail et al., 2022). Further analysis is warranted to discern the specific mechanisms through which financial inclusion influences the quality of the environment and to explore avenues for mitigating its adverse environmental effects within the context of comprehensive policy frameworks. Thus, we propose to conduct a moderation analysis. The moderation analysis involves examining how the relationship between two variables changes depending on the level of a third variable. It helps to understand the conditions under which the relationship between the main variables strengthens, weakens, or changes direction (see Muller et al, 2005; Fairchild and McKinnon, 2009; Jose, 2013; Judd et al., 2014). Before proceeding to such an analysis, we provide a fruitful discussion of results concerning each variable included in our model.

Table 4. Effect of financial inclusion on environmental sustainability.

Variables	Dep. Variable: logco2				Dep. Variable: logtge			
	FE	FE	FE	FE	FE	FE	FE	FE
loggdppp	0.3299***	0.3393***	0.3299***	0.3299***	0.4055***	0.4060***	0.4047***	0.4047***
	(3.385)	(3.377)	(3.428)	(3.428)	(5.119)	(5.161)	(5.157)	(5.157)
logtrade	-0.0699*	-0.0674*	-0.0690*	-0.0690*	-0.0425**	-0.0426**	-0.0425**	-0.0425**
	(-1.833)	(-1.799)	(-1.820)	(-1.820)	(-2.418)	(-2.381)	(-2.402)	(-2.402)
logfdi	0.0389***	0.0362**	0.0392***	0.0392***	0.0165	0.0161	0.0168	0.0168
	(2.953)	(2.619)	(3.012)	(3.012)	(0.973)	(0.949)	(0.991)	(0.991)
lognaturalresource	0.0914***	0.0932***	0.0910***	0.0910***	0.0420***	0.0422***	0.0417***	0.0417***
	(7.178)	(7.203)	(7.085)	(7.085)	(3.222)	(3.198)	(3.200)	(3.200)
logurban	0.7855***	0.7817***	0.7809***	0.7809***	1.1140***	1.1138***	1.1126***	1.1126***
	(4.188)	(4.205)	(4.195)	(4.195)	(8.537)	(8.492)	(8.530)	(8.530)
logenergyuse	-0.0229**	-0.0228**	-0.0229**	-0.0229**	-0.0296**	-0.0296**	-0.0297**	-0.0297**
	(-2.246)	(-2.160)	(-2.269)	(-2.269)	(-2.259)	(-2.233)	(-2.259)	(-2.259)
logindustry	-0.0238	-0.0235	-0.0239	-0.0239	-0.0012	-0.0010	-0.0012	-0.0012
	(-1.230)	(-1.213)	(-1.221)	(-1.221)	(-0.063)	(-0.051)	(-0.062)	(-0.062)
logfi_zee	0.0830***				0.0332**			
	(3.269)				(2.770)			
logfi_mmx		0.0794***				0.0250**		
		(3.213)				(2.659)		
logfi_softmax			0.0836***				0.0310***	
			(3.404)				(2.896)	
logfi_sigmoid				0.0836***				0.0310***
				(3.404)				(2.896)
_cons	-5.4950***	-5.5702***	-5.4802***	-5.4802***	2.5156***	2.5203***	2.5305***	2.5305***
	(-15.931)	(-17.061)	(-15.811)	(-15.811)	(12.776)	(13.389)	(13.267)	(13.267)
N°observations	498	498	498	498	498	498	498	498
Serial correlation at the 1st order (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heteroscedasticity (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cross-section dependence Pesaran (2015, 2021) (p-value)	0.848	0.890	0.855	0.855	0.004	0.003	0.004	0.004
Cross-section dependence Fan et al. (2015) (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE vs RE (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: t statistics in parentheses* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

As we explore the empirical results from an economic perspective, a wealth of valuable insights emerges, fostering an engaging discussion.

- **Financial inclusion:** When considering a multidimensional index of financial inclusion that encompasses aspects such as access, depth, efficiency, and stability, the relationship between increased financial inclusion and higher CO_2 emissions in emerging and developing countries gains further nuance. From an economic perspective, a positive relationship between financial inclusion and environmental degradation in emerging and developing countries implies a need for careful consideration of the trade-offs between economic development and ecological sustainability. If increased financial inclusion is associated with environmental degradation, it suggests that the economic activities spurred by improved access to financial services and efficient and stable institutions may have negative environmental externalities. This scenario underlines the importance of aligning economic policies with environmental conservation efforts. Policymakers should explore strategies to decouple economic growth from environmental harm, perhaps by incentivizing green investments, promoting sustainable business practices, and integrating environmental impact assessments into financial policies. Balancing the pursuit of economic development with environmental stewardship becomes crucial to ensure a more sustainable and inclusive growth trajectory for these nations. We note similarities between this finding and the ones of several studies such as Le et al. (2020), Wang et al. (2022a), Wang et al. (2022b), Mehmood (2022), Zaidi et al. (2022), Chaudhry et al. (2022), Fareed et al. (2022), Khan et al. (2023a, 2023b), Tsimisaraka et al. (2023), Mukalayi and Inglesi-Lotz (2023), and Hussain et al. (2023). Nevertheless, we depict a contradicting finding in the works of Baskaya et al. (2022) who argued that financial inclusion is a catalyst for growth while alleviating CO2 emissions in Brazil, Russia, China, and South Africa (BRICS) nations. Based on panel ARDL models, Du et al. (2022) claimed that financial inclusion is environment-enhancing. Feng et al. (2022) recognized a negative long-term impact of the number of ATMs on CO2 emissions in China. The difference stems from many sides such as considering limited aspects of financial inclusion, the focus on other regions, and the use of a different time coverage.

The economic implications of financial inclusion, which concurrently leads to an increase in both carbon dioxide (CO2) emissions and total greenhouse gas emissions in emerging and developing countries, highlight the importance of adopting carefully calibrated policies. Striking a balance between economic development and environmental sustainability becomes imperative. Policymakers may consider implementing incentive structures that encourage investments in clean energy technologies and environmentally friendly practices. Additionally, targeted regulations could be introduced to mitigate the negative externalities associated with increased industrial production and energy consumption resulting from financial inclusion. A comprehensive approach may involve integrating environmental impact assessments into financial inclusion strategies, guiding stakeholders toward sustainable choices. Collaborative efforts with the private sector to foster green investments and innovations can also play a pivotal role. The challenge lies in crafting policies that harness the economic benefits of financial inclusion while proactively addressing its ecological consequences, thereby fostering a harmonious and sustainable development trajectory.

- **Income per capita:** In contrast to the impact of financial inclusion on environmental quality, our research aligns with previous empirical studies (mentioned above) indicating a positive relationship between GDP per capita and environmental degradation. However, it deviates from the findings reported by Liu et al. (2022). Our results suggest that the conventional belief of the Environmental Kuznets Curve is not applicable in the context of the studied countries. Our finding indicates that, in this context, increasing economic prosperity may exacerbate environmental degradation. This emphasizes the pressing need for carefully tailored and sustainable development strategies in these regions.
- **Foreign direct investment:** The proposition put forth by Le et al. (2020) and Achuo et al. (2022) regarding the adverse impact of increasing foreign direct investments (FDI) on environmental degradation holds for the countries considered in our sample. This implies that the pursuit of heightened FDI inflows may be associated with negative environmental consequences. Policymakers and stakeholders need to carefully assess the trade-offs between attracting foreign investments and preserving environmental quality. This finding suggests a critical need for the integration of environmental considerations into FDI policies, with an emphasis on implementing

sustainable practices and stringent environmental standards for foreign investors. Additionally, it emphasizes the importance of aligning economic development strategies with environmental conservation goals, striking a balance between attracting investments for growth and ensuring that such growth is environmentally responsible. As the debate surrounding FDI's impact on the environment continues, these implications call for a nuanced and integrated approach to economic and environmental policymaking in the studied regions.

- **Trade openness:** Increasing the share of imports and exports is seen as an effective tool for environment enhancement, confirming the observations of Le et al. (2020) and Achuo et al. (2022). Contrary to the observations of Mehmood (2022) and Hussain et al. (2023), our results imply that globalization and increased trade openness contribute positively to environmental sustainability. Policymakers may find value in crafting trade policies that encourage sustainable practices and eco-friendly technologies. This emphasizes the potential for international trade to act as a catalyst for positive environmental outcomes in emerging and developing countries.
- **Urban population:** It is not surprising to find that an upward trend in urban population size lessens the quality of the environment. This finding joins previous findings of Bai et al. (2019), Le et al. (2020), and Liu et al. (2021a). The expansion of urban areas often brings about intensified industrial activities, heightened energy consumption, and increased vehicular traffic, all of which contribute to environmental stress. This consistency across studies underscores the robustness of the relationship between urbanization and environmental degradation. From an economic perspective, it emphasizes the urgent need for sustainable urban planning and development strategies. Policymakers should prioritize initiatives that integrate environmental considerations into urbanization plans, promoting eco-friendly infrastructure, green spaces, and energy-efficient technologies. Additionally, fostering public awareness and engagement in sustainable urban living practices becomes crucial.
- **Energy use:** The assertion that higher levels of the energy intensity level of primary energy are environmentally enhancing may seem counterintuitive but has been substantiated in research, as exemplified by Acheampong (2018) in the context of African, Latin American, and Caribbean regions. The apparent paradox arises from the understanding that more intense use of primary energy when coupled with technological advancements and a transition to cleaner energy sources, can contribute to reduced CO2 emissions per unit of energy consumed. Acheampong (2018) suggests that strict energy conservation policies, while aimed at reducing overall energy consumption, may inadvertently lead to an increase in carbon emissions.
- **Natural resource rents:** The positive impact of natural resource rents on CO2 emissions and total greenhouse gas emissions, as observed in studies like Du et al. (2022), carries significant economic implications for emerging and developing countries. This relationship suggests that the reliance on income generated from natural resource extraction, such as oil, gas, or minerals, may contribute to increased carbon emissions in these regions. Economic dependence on natural resource rents often leads to the development of resource-intensive industries, which can result in environmental degradation and higher greenhouse gas emissions. For policymakers in emerging and developing countries, this finding underscores the need for diversifying the economy and reducing dependency on natural resource extraction. While these resources can provide crucial revenue, the associated environmental costs necessitate careful consideration.
- **Industry:** The observed negative impact of the share of industry to GDP on environmental degradation, while not statistically significant, hints at a potential association between industrial activity and lower carbon emissions. This result diverges from the findings of Le et al. (2020) and Hussain et al. (2023), who presumably identified a more pronounced or significant positive relationship between industrial share and CO2 emissions but aligns, partially, with the conclusions drawn by Wang et al. (2022a), suggesting that a larger industrial sector, relative to the overall economy, may not necessarily be a major contributor to increased carbon emissions. While the lack of statistical significance warrants careful interpretation, the negative direction implies that, under certain circumstances, a

larger industrial sector relative to the overall economy may not necessarily contribute significantly to increased carbon emissions.

4.3. The role of control of corruption and trade openness: Is there a moderating effect?

Financial inclusion initiatives have the potential to alleviate corruption by promoting transparency and accountability in financial transactions, thus fostering a more robust regulatory environment (see Barik and Lenka, 2023; Jungo et al., 2023). We analyze what mechanisms can alleviate the positive effect of financial inclusion on environmental sustainability through the moderation analysis. In our view, financial inclusion increases CO2 emissions but control of corruption can aid in administering CO2 emissions (Liu et al., 2021). Corruption pertains to the abuse of public power for personal interests (Barik and Lenka, 2023). Misconduct of public authorities is expected to have a pronounced impact on other socio-economic outcomes including financial development (see Khemani and Meyerman 1998; Song et al. 2021; Weill, 2011a, b; Park 2012). Theoretically, corruption and financial development (inclusion) are interrelated. The 'sand and the wheels' hypothesis posits that corruption damages the development of the financial sector (Group, 2017). The opinion emerges as follows. Whenever transparent and supervised systems are missed, improper allocation of financial resources increases, leading to financial instability (Sharma, 2021; Alshubiri, 2021). The causal direction can work in the other way. Put simply, building transparent organizations through digital technology shifts misconduct downward. Thus, financial inclusion decreases corruption (Barik and Lenka, 2023). The process might be, however, asymmetric, implying that increases in corruption may be beneficial for financial development (Alsagr and van Hemmen, 2021). The 'grease and the wheels' hypothesis states that corruption stands against discrimination among private agents some of whom do not access markets, which increases financial efficiency (Beck and Mahler, 1986; Lien, 1986). Indeed, ineffective regulations pose barriers to investment that can be subordinated by paying off bureaucrats (Dreher and Gassebner, 2013). Since controlled corruption contributes to a green environment and plays a pivotal role in the development of the financial sector, it is likely to intervene to alter the financial inclusion -environmental pollution relationship.

We augment Equation (2) with the product of financial inclusion and a moderating variable (MOD).

$$LOGY_{it} = \alpha_{it} + \theta_1 LOGFI_{it} + \theta_2 LOGMOD_{it} + \pi LOGFI_{it} \times \mathrm{LOGMOD_{it}} + \beta'\mathrm{LOGX_{it}} + \varepsilon_{it} \quad (3)$$

First, we estimate Equation (3) when MOD is control of corruption. Results of Table 5 suggest that efforts to address corruption contribute to improved governance, leading to a higher quality environment. Notably, the coefficient associated with financial inclusion remains positive and statistically significant across all composite PCA indices, even after accounting for the interaction term (logfi_mod).[5] This highlights the persistent impact of financial inclusion on environmental sustainability. Controlling corruption does not however disturb the financial inclusion-environmental sustainability pattern. The prevalence of corruption in emerging and developing countries makes its control still insufficient to prevent the transmission of the adverse effect of financial inclusion on environmental sustainability. While financial inclusion is often celebrated for its potential to stimulate economic growth and alleviate poverty, our findings emphasize the necessity of considering its environmental implications. There is a need for a comprehensive policymaking approach that integrates environmental concerns into development strategies, ensuring a balanced consideration of the benefits and potential costs of financial inclusion. These insights hold critical importance for policymakers seeking to foster sustainable development trajectories in emerging and developing

[5] We have estimated the panel regression including control of corruption without the interaction term. We depict a negative and a highly and statistically significant effect of control of corruption on CO2 emissions. The results are not shown to save space but are available upon request from the authors.

economies.

Table 5. Effect of financial inclusion on environmental sustainability: Moderating effects.

Variables	Moderating variable: control of corruption (logcc)				Moderating variable: trade openness (logtrade)			
	FE	FE	FE	FE	FE	FE	FE	FE
loggdppp	0.4022***	0.4101***	0.4001***	0.4001***	0.3332***	0.3414***	0.3344***	0.3344***
	(3.638)	(3.733)	(3.670)	(3.670)	(3.478)	(3.431)	(3.551)	(3.551)
logtrade	-0.0835**	-0.0821**	-0.0835**	-0.0835**	0.0297	0.0591	0.0441	0.0441
	(-2.412)	(-2.448)	(-2.461)	(-2.461)	(0.408)	(0.896)	(0.590)	(0.590)
logfdi	0.0421**	0.0400**	0.0428***	0.0428***	0.0373**	0.0350**	0.0376**	0.0376**
	(2.786)	(2.493)	(2.884)	(2.884)	(2.774)	(2.431)	(2.798)	(2.798)
lognaturalresource	0.0912***	0.0918***	0.0907***	0.0907***	0.0826***	0.0821***	0.0799***	0.0799***
	(5.595)	(5.401)	(5.484)	(5.484)	(5.742)	(5.810)	(5.304)	(5.304)
logurban	0.6559***	0.6501***	0.6551***	0.6551***	0.7908***	0.7908***	0.7841***	0.7841***
	(3.603)	(3.695)	(3.646)	(3.646)	(4.009)	(3.968)	(3.983)	(3.983)
logenergyuse	-0.0288**	-0.0288**	-0.0289***	-0.0289***	-0.0207**	-0.0195*	-0.0204*	-0.0204*
	(-2.799)	(-2.736)	(-2.854)	(-2.854)	(-2.083)	(-1.906)	(-2.067)	(-2.067)
logindustry	-0.0207	-0.0208	-0.0207	-0.0207	-0.0247	-0.0249	-0.0252	-0.0252
	(-0.900)	(-0.894)	(-0.888)	(-0.888)	(-1.310)	(-1.324)	(-1.331)	(-1.331)
logcc	-0.2293	-0.2496	-0.2284	-0.2284				
	(-1.642)	(-1.701)	(-1.640)	(-1.640)				
logfi_zee	0.0368				0.3656**			
	(0.754)				(2.260)			
logfizee_mod	0.1625				**-0.0689***			
	(1.163)				**(-1.795)**			
logfi_mmx		0.0235				0.4449***		
		(0.466)				(3.000)		
logfimmx_mod		0.1826				**-0.0892****		
		(1.247)				**(-2.516)**		
logfi_softmax			0.0357				0.4043**	
			(0.709)				(2.498)	
logfisoftmax_mod			0.1688				**-0.0783***	
			(1.177)				**(-2.016)**	
logfi_sigmoid				0.0357				0.4043**
				(0.709)				(2.498)
logfisigmoid_mod_				0.1688				**-0.0783***
				(1.177)				**(-2.016)**
_cons	-5.5303***	-5.5692***	-5.5082***	-5.5082***	-5.9511***	-6.1387***	-5.9914***	-5.9914***
	(-10.987)	(-11.394)	(-11.127)	(-11.127)	(-13.154)	(-14.681)	(-13.214)	(-13.214)
N°observations	434	434	434	434	498	498	498	498
Serial correlation at the 1st order (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Heteroscedasticity (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cross-section dependence Pesaran (2015, 2021) (p-value)	0.803	0.807	0.782	0.782	0.756	0.758	0.758	0.758
Cross-section dependence Fan et al. (2015) (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FE vs RE (p-value)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Notes: t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Second, we conduct a replication of the estimations outlined in Equation (3) where financial inclusion interacts with trade openness. It is known that trade openness can be determined through technological advancement. We rely on the hypothesis of Porter and Van der Linde (1995) who asserted that more stringent environmental regulations stimulate technological innovation and competitiveness and, consequently, have positive effects on both the economy and the environment, through energy savings.

A school of thought argues that trade openness affects both the supply and the demand of external finance. From the supply side, trade liberalization lessens firm entry to plug financial development (Rajan and Zingales, 2003; Braun and Raddatz, 2005). From the demand side, trade openness increases the need for financial services to diversify risks to exogenous shocks and competition (Svaleryd and Vlachos, 2002). Empirically, trade openness-financial development nexus is fruitful according to Kim et al. (2010) and Zhang et al. (2015). At the same time, trade intensity perturbs emissions in CO2 through increasing production and growth, helping the transition to a decarbonized world (Antweiler et al., 2001). We portray this effect as scale and technique effects. The 'scale' effect of increased trade, transport, and production (more efficient allocation of resources) is generally negative for the environment. Trade can be a source of pressure on the climate, biodiversity, air, and water quality. The ‘technique’ effect facilitates the availability and deployment of clean technologies (renewable energies, etc.) and reduces their cost. This is good for the environment.

The environmental aftermath of trade openness can be attributed to the composition effect (Managi et al., 2009; Sbia et al., 2014; Farhani and Ozturk, 2015). The ‘composition’ effect corresponds to the fact that all the goods produced by a region can evolve according to its comparative advantages and the greater or lesser extent to which they can be exploited following the opening up of trade. For example, a region may specialize in certain cleaner forms of production or, on the contrary, change the way it uses its land (depending on the comparative advantage of each country, specialization in agriculture and livestock farming may contribute to the displacement of pioneer fronts and deforestation). Because the polluting industry is capital-substantial, a more capital-rich country produces more pollution (Tayebi and Younespour, 2012). In the context of emerging and developing countries, trade openness can be an engine to achieve a better quality environment (Pham and Ngyuen, 2022).

Our analysis, presented in the second part of Table 5, indicates that the interaction term (logfi_mod) exhibits a statistically significant negative effect on CO2 emissions per capita. This finding suggests that not only trade openness facilitates the adoption of cleaner technologies and promotes sustainable practices through international cooperation but also contributes to mitigating environmental degradation exacerbated by increases in financial inclusion levels. Our results differ from Ullah et al. (2022) who found that financial inclusion improves environmental sustainability and that globalization helps fostering this relationship in OECD countries. Furthermore, we disagree with Zhao et al. (2022) who showed an undesirable effect of economic globalization on the quality of the environment.

5. Conclusion and policy implications

Our study rigorously examined the relationship between financial inclusion and environmental quality, with a special emphasis on emerging and developing countries. The unequivocal findings establish a significant and positive link, indicating that increased financial inclusion contributes notably to lower environmental sustainability. The robustness of these results, verified through the application of four composite indices using PCA, emphasizes the reliability and generalizability of our observations. Importantly, the implications of this research extend beyond academic discourse to practical, policy, and managerial domains. Policymakers can draw upon these findings to formulate informed strategies that integrate financial inclusion and environmental conservation efforts, fostering sustainable development. Moreover, businesses and financial institutions can utilize the insights to align their practices with environmentally responsible principles. In essence, this study contributes valuable knowledge to the ongoing discourse on the intersection of finance and environmental sustainability, offering practical guidance for decision-makers in diverse sectors. We argue that governments in emerging and developing countries should design policies that fulfill both financial development and sustainable goals by encouraging trade. In our view, the environmental benefits are inferred from the 'technique' or 'composition' effect of trade openness. International trade, through the rationalization it induces and the efficiency it generates, promotes better environmental protection. Nevertheless, the ‘scale’ effect could not be excluded and the negative impact of trade openness might show up in the context of our sample. Instead of reducing emissions by blocking the growth of international trade, which would be very costly in

terms of economic growth and not very effective for the environment, we need to regulate trade emissions. To do this, the various branches of international regulation have to work together more effectively, to ensure that climate cooperation flourishes (Bureau et al., 2017). Future research should breakdown the 'scale', 'technique', and 'composition' effects to disentangle the benefits and drawbacks of trade openness on the environment separately.
Moreover, the prevalence of corruption is alarming in these nations. This entails investing resources and implementing reforms aimed at upgrading levels of governance. There is a need to identify and address potential corruption weaknesses in key government institutions, policies, and practices. Authorities must improve current management systems to promote cross-checking of standards to prevent abuse. By making public the criteria, structures, and procedures for awarding contracts and procurement for major infrastructure projects, corruption can be reduced. Governments can strengthen the accountability and integrity of institutions and decision-makers, for example by actively carrying out environmental audits and strictly enforcing laws.

While PCA presents advantages over constructing composite indices (Mazziotta and Pareto, 2017), it does not properly identify complex relationships between selected indicators. Advanced techniques such as machine learning should be considered in this area. Future research could investigate the impact of financial inclusion on fostering financial innovation within diverse economic contexts. Exploring the role of inclusive financial practices in stimulating technological advancements, such as digital banking and fintech solutions, would provide valuable insights. Moreover, understanding how financial innovation, in turn, contributes to greater accessibility and inclusivity in financial services could be a crucial area for further exploration.

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Conflict of interest

All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest All the authors claim that the manuscript is completely original. The authors also declare no conflict of interest.

Appendix

Table A.1. PCA results.

Method	**Bartlett test of sphericity**			**Kaiser-Meyer-Olkin sampling adequacy measure**
	Chi-square	Degree of freedom	P-value	
Normalization with Z-score	24505.290	528	0.000	0.737
Normalization with Min-Max	24505.290	528	0.000	0.737
Normalization with Softmax	25173.593	528	0.000	0.745
Normalization with Sigmoid	25173.593	528	0.000	0.745

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