Does financial inclusion spur CO_2 emissions? The marginal effects of financial sustainability

Yusuf Adeneye
Faculty of Hospitality, Tourism and Wellness, Universiti Malaysia Kelantan, Pengkalan Chepa, Malaysia
Shahida Rasheed
Department of Commerce, University of Kashmir, Srinagar, India, and
Say Keat Ooi
Graduate School of Business, Universiti Sains Malaysia, Gelugor, Malaysia

Received 28 February 2023
Revised 28 June 2023
18 July 2023
14 September 2023
Accepted 16 September 2023

Abstract

Purpose – This study aims to examine the relationship between financial inclusion, CO_2 emissions and financial sustainability across 17 African countries.

Design/methodology/approach – Data were sourced from the World Development Indicators for the period 2004-2021. The study performs the principal component analysis, panel fixed effects model and quantile regression estimations to investigate the relationship between financial inclusion, CO_2 emissions and financial sustainability.

Findings – The study finds that an increase in automated teller machine (ATM) penetration rate, savings and credits increases CO_2 emissions. Findings also reveal that financial sustainability reduces financial inclusion, with significant negative effects on the conditional mean of CO_2 emissions and the conditional distribution of CO_2 emissions across quantiles.

Originality/value – This study is beneficial for policymakers, particularly in the age of digitalization and drive for low-carbon emissions, to develop green credits for energy players and investors to take up renewable and green energy projects characterized by high levels of carbon storage and carbon capture. Further, the banking sector's credits and liquid assets should be used to finance alternative banking energy-related equipment and services, such as solar photovoltaic wireless ATMs, and fewer bank branches.

Keywords Financial inclusion, Financial sustainability, CO_2 emissions, Partial differentiation

Paper type Research paper

1. Introduction

Contemporary research on CO_2 emissions reports that financial inclusion involving bank account ownership, automated teller machine (ATM) penetration rate, savings and credits drive the total amount of CO_2 emissions (e.g. Le, Le, & Taghizadeh-Hesary, 2020). However, with the drive for low-carbon emissions, the financial system must play a significant role in reducing CO_2 emissions by ensuring financial sustainability through the redistribution of more bank credits and liquid assets to finance renewable and nonrenewable energy initiatives. This study leverages World Development Indicators (WDIs) annual data from

---

JEL Classification — E51, G21, Q43, Q56

Funding: This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

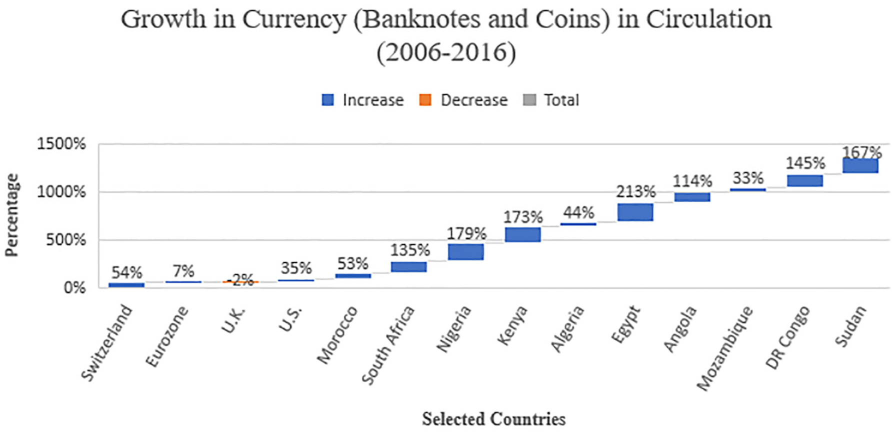
IIMBG Journal of Sustainable Business and Innovation
Vol. 1 No. 2, 2023
pp. 77-97
Emerald Publishing Limited
2753-4022
DOI 10.1108/IJSBI-02-2023-0004

African countries to present new evidence to inform the policy implications of financial sustainability on financial inclusion and CO_2 emissions. Understanding the link between the financial industry and environmental pollution in Africa is crucial (Abid, 2016) since most African countries are characterized by poor energy development, increased use of paper notes and the increase in the number of automated teller machines (ATMs) and bank branches in a way to foster financial inclusion. However, such unsustainable paper notes and the carbon emissions from ATMs, bank branches and light vehicles (i.e. that consume more fossil fuels) that are used to transport paper notes from one bank to the other contribute to the increasing rate of CO_2 emissions in Africa (see Supplementary Table S1). For instance, ATMs emit about 3.2 million tons of $CO_{2,}$ while bank branches emit 383.1 million tons of CO_2 yearly (McCook, 2014). The environmental impact of an average cash transaction is 5.1g CO_2 equivalent with the energy use of ATMs, and currency transportation contributing about a 64% impact on the environment, while the production of coins contributes about 31% impact on the environment (Hanegraaf, Larçin, Jonker, Mandley, & Miedema, 2020). Also, banknotes weighing 93.4 tons emit approximately a volume of 1.6 million tons of CO_2 equivalents (Wettstein, Lieb, & Lieb, 2000).

Indeed, the activities of the financial sector through financial inclusion can exert both direct and indirect effects on environmental pollution and contribute significantly to the total amount of CO_2 emissions. The overall cash in circulation worldwide across countries continues to grow between 5% and 8% annually (Currency Research, 2017). In Spain, for example, 42% of people said that they prefer using cash (Esselink & Hernández, 2017). Interestingly, the existence of Covid-19 may indirectly contribute to CO_2 emissions. The United Nations (2020) confirmed that cash has been used to fight Covid-19 only in the developing world. While one would expect that CO_2 emissions should decrease during Covid-19 due to the stoppage in production across industrial and manufacturing firms, the circulation of cash as an economic palliative may still give rise to CO_2 emissions. In Sweden, the cost of ATM cards and cash amounts to about 0.4% of gross domestic products, causing negative externalities through CO_2 emissions (Bergman, Guibourg, & Segendorf, 2008). The growth in currency in circulation between 2006 and 2016 is over 100% in many African countries when compared to the Eurozone and the UK, where it is −2.5% (As in Figure 1). Also, the number of individuals who visit bank branches and ATMs with their light vehicles that use fossil fuels contributes to CO_2 emissions in G-20 countries (Erdoğan, Taiwo, Altuntaş, & Victor, 2022). Internal combustion vehicles that bank use for cash transportation operations emit large quantities and amounts of CO_2 equivalent (Bank of Finland, 2020). For instance, banking firms can contribute to indirect pollution by lending money to polluting companies or engaging in projects that cause major damage to the environment (Zhang, Yang, & Bi, 2011).

How, then, can we minimize or mitigate the effects of financial inclusion on CO_2 emissions? The most important way is to ensure the sustainability of the financial industry through financial sustainability, which, in turn, can reduce the negative effects of financial inclusion on CO_2 emissions (In Bouma, Jeucken, & Klinkers, 2017). The availability of more bank liquid assets to finance renewable ATMs is important to reduce the carbon emissions that are emitted through ATMs. Equally, the enablement of green credit policy including more online transactions than cash payments, and the granting of more credits from bank deposits to energy policy actors and players to finance renewable energy, would further reduce the environmental effect of the financial industry (Zhang *et al.*, 2011). By extension, banks' credit policy meets a green standard where more credits are granted to firms that comply with environmental pollution standards, and that credit granted is made through transfer options rather than through cash payments.

Several studies have examined the role played by financial inclusion in African contexts. For example, Zins and Weill (2016) examined the determinants of financial inclusion in Africa



Note(s): Data used to plot this graph were obtained from the Africa Development Indicators (https://databank.worldbank.org/source/africa-development-indicators/Series/FM.LBL.MONY.CN#), OECD Database (https://data.oecd.org/money/narrow-money-m1.htm), and International Monetary Fund (https://databank.worldbank.org/metadataglossary)

Source(s): Figure provided by author

Figure 1.
Growth in currency in circulation (i.e. narrow money) between 2006 and 2016

and found that education, income and mobile banking drive formal accounts, savings and credit in 37 African countries, using probit estimations. In another study, the use of mobile telephony promotes the likelihood of savings for financial inclusion in Kenya, Malawi, Uganda and Zambia (Ouma, Odongo, & Were, 2017). Gebrehiwot and Makina (2019), using the GMM dynamic panel in 27 African countries, found that financial inclusion positively affects economic growth, while negatively affecting government borrowing. However, whether financial sustainability mitigates the negative impacts of financial inclusion on CO_2 emissions is understudied.

Against this backdrop, this study investigates the impact of financial inclusion on carbon emissions along with the marginal effect of financial sustainability on the relationship between financial inclusion and CO_2 emissions (finance-environment nexus) in 17 African countries over the period 2004-2021. The significant contribution of this study to the understanding of the finance-environment nexus is as follows. Firstly, concerning CO_2 emissions, most studies in the African setting have been linked to economic growth, financial development, sustainable goals, globalization and renewable energy (e.g. Raheem, Tiwari, & Balsalobre-Lorente, 2020; Wang, Mirza, Vasbieva, Abbas, & Xiong, 2020; Zaidi, Zafar, Shahbaz, & Hou, 2019) with the conclusion that CO_2 emissions retard economic growth, and its effects can be reduced through renewable energy and sustainable developmental goals. These studies fail to investigate the link between financial inclusion and CO_2 emissions in African studies and the policy design concerning financial sustainability to reduce the likely negative effects of financial inclusion on CO_2 emissions. Secondly, existing literature (e.g. Li & Wei, 2021) has focused mainly on investigating the environmental impacts of financial development. Specifically, previous studies have often relied on indicators such as domestic credit to the private sector, as a measure of financial development. To bridge the existing gap, this study develops a holistic financial inclusion index by incorporating diverse indicators of financial inclusion to evaluate the finance-CO_2 emission nexus. Thirdly, since SGD-17 and the Paris Agreement 2015 have acknowledged the significant influence of financial sustainability on emission levels, this study examines the combined impact of financial sustainability and financial inclusion on carbon dioxide emissions in the selected African nations. Prior studies have largely ignored the channels by which the financial sector and promoting financial sustainability can collectively contribute to lowering CO_2 emissions in the African context.

The rest of the paper is organized as follows. Section 2 presents a review of related literature that leads to the research gaps and development of research hypotheses. Section 3 provides the data source and methods, while section 4 presents the results and discussions. Section 5 presents the conclusion and policy implications.

2. Literature review

This section presents the literature that forms the development of our hypotheses, and thus the gap for the study.

H1. Financial inclusion promotes CO_2 emissions.

The studies on the relationship between financial inclusion and CO_2 emissions are beginning to increase. For instance, using Hoechle's (2007) model for Driscoll-Kraay standard errors, Le *et al.* (2020) investigated the effect of financial inclusion on CO_2 emissions for 31 Asian countries and showed that financial inclusions appear to promote increased CO_2 emissions. Although financial inclusion is an integral part of financial development (Le *et al.*, 2020; World Bank, 2018), most of the studies, except for Le *et al.* (2020), have linked financial development with CO_2 emissions. As reported by Abbasi and Riaz (2016), financial development promotes, and does not aid, the reduction of CO_2 emissions in Pakistan by adopting ARDL and augmented VAR models. Charfeddine and Kahia (2019) established that financial development enhances CO_2 emissions in 24 countries in the Middle East and North Africa region, using the PVAR model estimator, impulse response function and variance decomposition. The weak financial development in MENA countries does not contribute to environmental quality by reducing CO_2 emissions. Raheem *et al.* (2020) reported that financial development has a weak effect on CO_2 emissions in G7 countries, using the pooled mean group estimator. Shoaib, Rafique, Nadeem and Huang (2020) conducted a comparative analysis between developed (G8) and developing countries (D8) and found that financial development has significant positive effects on CO_2 emissions in G8 and D8 countries, using the PMG panel ARDL estimator, which is in support of Wang *et al.* (2020) that study N-11 countries. Using a structural break test, Toda-Yamamoto causality and cointegration models, Shahbaz, Haouas, Sohag and Ozturk (2020) established that financial development positively affected CO_2 emissions and environmental degradation in the United Arab Emirates between 1975 and 2014. In contrast, Zaidi *et al.* (2019) established that financial development retards CO_2 emissions both in the long run and short run, using Westerlund cointegration, continuously updated fully modified and continuously updated bias-corrected estimation techniques on sample data of Asia Pacific Economic Cooperation. Similarly, Wang *et al.* (2020) found that financial development reduces CO_2 emissions in the long run in Turkey. Nasir, Huynh and Tram (2019) confirm, using dynamic ordinary least squares and fully modified OLS on a sample of ASEAN-5 economies, that financial development increases CO_2 emissions in the long run. Khan, Peng and Li (2019) further emphasized that financial development positively impacts CO_2 emissions with high pollution spread, using dynamic GMM and seemingly unrelated regression (SUR) on a panel of 193 countries. Guo, Hu and Yu (2019) established that financial development efficiency increases CO_2 emissions, while the financial development scale reduces CO_2 emissions in China, using the STochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model of environmental pressure. Also, Tian and Li (2022) confirm that financial inclusion increases carbon emissions, using the CS-ARDL and VECM Granger causality method, positing that the availability of financial services boosts funding for more industrial and manufacturing operations, which raises demands for and consumption of fossil fuels.

Similarly, Zaidi *et al.* (2019) advocate that financial inclusion increases carbon emissions in OECD and BRICS countries through increased economic activity, and access to credit leads to more carbon-intensive financing activities such as transportation or manufacturing. Hussain, Akbar, Gul, Shahzad and Naifar (2023) found that when individuals and businesses have access to affordable financial resources, it can positively affect carbon emissions in the short run only. However, beyond a certain threshold, the accessibility of credit at a reduced cost of capital increases corporate production capacity and energy-intensive household appliances. Another study by Tsimisaraka *et al.* (2023) advocates that easier access to credit exhibited a greater propensity to purchase a variety of products, such as automobiles and refrigerators, which has contributed to a greater demand for energy derived from fossil fuels, thereby increasing the carbon dioxide (CO_2) emissions. These findings are supported by Jebli and Hakimi (2023), suggesting that companies tend to invest in non-environmentally friendly projects using financial services. Thus, this contributes to an increase in the consumption of energy derived from fossil fuels. Accordingly, the literature on the link between financial development and CO_2 emissions is vast and varies in a contextual sense, an indication that assessing its integral parts such as financial inclusion may enhance our understanding of CO_2 emissions in a particular context.

The results of these brief studies reveal some differences. The differences are due to the context in which the study is conducted, the type of estimation techniques, the sample size of the study, the period of study, the kind of theories adopted and the nature of the country (whether developing vs developed countries, the level of per capita income and economic growth and the level of financial structure that exists in the country understudied). Interestingly, one major similarity is that these studies focus on financial development emission linkages. In this paper, we further add to the finance-environment nexus, extending the study of Le *et al.* (2020), by examining the role that financial inclusion plays in promoting CO_2 emissions across countries in Africa.

H2. Financial sustainability reduces the impact of financial inclusion on CO_2 emissions.

Several studies have posited that the increasing level of financial constraints is one of the major bottlenecks to taking up renewable and non-renewable energy policies. Supporting this claim, Baulch, Do, and Le (2018) submit that lack of access to capital and lack of credits and loanable funds from government and financial institutions have resulted in a serious barrier in the fight against the reduction of CO_2 emissions in Vietnam. Meanwhile, Le *et al.* (2020) buttressed that the availability of affordable financial services that can promote the reduction of CO_2 emissions by using alternative fossil fuels and gas such as CO_2 capture and CO_2 storage is relevant in the adoption of environmental sustainability programs. Further, Bayram, Talay, and Feridun (2022) argued that sustainable finance can help to assess climate-related financial risks, which can potentially lead to a reduction in emissions by incentivizing firms to invest in sustainable practices. Moreover, Wan, Pu, and Tavera (2023) claim that financial sustainability through digital finance reduces pollution through innovations, sustainable capital allocation effects and structural adjustments. Similarly, Cao (2023) argued that financial sustainability can be boosted through green finance projects. Another study by Kirikkaleli, Adebayo, and Güngör (2021) submit that sustainability can be accelerated by financing renewable energy technologies and research and development through financial development. Most studies that have linked financial inclusion and financial development having negative effects on CO_2 emissions (e.g. Cao, 2023), imply that sustainable finance, hence financial sustainability, is required to enhance and promote the reduction of CO_2 emissions.

While several studies have suggested different financial strategies and policies for reducing CO_2 emissions using consumption-based carbon tax and other public finance strategies including green finance and digital finance (Bouwer & Aerts, 2006; Wan *et al.*, 2023), two questions are yet to be answered. First, how sustainable is the financing of CO_2 emissions reduction? Second, to what extent can the financing sustainability reduce CO_2 emissions for policy formulation and implementation? Both questions are important because countries differ in terms of the capital market, availability of funds and foreign aid and the level of technological advancement. For instance, most capital markets in Africa are undervalued, and the financial system is less developed to finance CO_2 emissions reduction goals. African countries that are also battling with issues of unemployment, incessant domestic war and insecurity have fewer funds to finance CO_2 emissions. The demand for foreign aid and inflows of energy technologies into Africa has been increasing in the recent decade (Udi, Bekun, & Adedoyin, 2020). Furthermore, better financial sustainability such as energy players' access to domestic credits to finance CO_2 emissions reduction will enable the government to have long-term solutions to the energy problem and the environmental problems of CO_2 emissions. Government political trust may also be required to promote financial sustainability by ensuring manufacturing and industrialized companies pay suitable tax rates.

To our knowledge, fewer empirical studies have investigated the role of financial sustainability in reducing the positive effect of financial inclusion on CO_2 emissions in Africa. However, studies have identified a few indicators of financial sustainability in financing CO_2 emissions reduction such as bank sector development, that is, the ratio of bank credit to bank deposits (Zafar, Zaidi, Sinha, Gedikli, & Hou, 2019), bank credit to the private sector (Nwani & Omoke, 2020) and liquid assets (Monasterolo & Raberto, 2019). We provide how these financing strategies, grouped as financial sustainability indicators, reduce the positive links between financial inclusion and CO_2 emissions.

3. Data and methods

This study utilizes the panel fixed effects model and quantile regression technique to examine the relationships between financial inclusion, financial sustainability and CO_2 emission across 17 African countries for the period 2004-2021. The description of the variables is presented in Supplementary Table S2. A principal component analysis was performed on the two measures of financial sustainability that support the study of Le, Chuc and Taghizadeh-Hesary (2019). The study controls for GDP, GDP square, energy consumption, trade openness, urbanization and political stability.

3.1 Fixed effect model

Fixed effects estimation is a statistical technique for investigating non-experiment data. It enables the researcher to control individual-specific characteristics that remain constant over time but may be correlated with the predictor variables and exert their influence on the predicted variable (Baltagi and Giles, 1998). These characteristics could encompass unobservable traits or contextual factors that vary across individuals but remain constant over time (Schmidheiny & Basel, 2011). It addresses the potential endogeneity and omitted variable biases that arise in panel data. The fixed effects model provides unbiased estimates of a casual effect than ordinary regression. Therefore, the fixed effects model equation can be written as follows:

$$
\begin{aligned}
lnCO2e_{it} = {} & \beta_0 + \beta_1 lnAccountsOwnership_{it} + \beta_2 lnATMPenetrationRate_{it} \\
& + \beta_3 lnSavings_{it} + \beta_4 lnCredits_{it} + \beta_5 lnFS_{it} \\
& + \beta_6 lnAccountsOwnership{*}FS_{it} + \beta_7 lnATMPenetrationRate{*}FS_{it} \\
& + \beta_8 lnSavings{*}FS_{it} + \beta_9 lnCredits{*}FS_{it} + \beta_{10} lnGDP_{it} \\
& + \beta_{11} lnGDPsquare_{it} + \beta_{12} lnEnergycons_{it} + \beta_{13} lnTradeopeness_{it} \\
& + \beta_{14} lnUrbanization_{it} + \beta_{15} lnPoliticalStability_{it} + \mu_{it}
\end{aligned}
\tag{1}
$$

3.2 Marginal effects model

The interaction term between financial inclusion measures (accounts ownership, ATM penetration rate, savings and credits) and financial sustainability is expected to increase our understanding of the CO_2 emissions equation. At the margin, the effect of financial inclusion measures (accounts ownership, ATM penetration rate, savings and credits) and/or financial sustainability can be calculated by using the interaction model of Brambor and Golder (2006), examining the partial derivative or partial difference of CO_2 emissions concerning each of the indicators of financial inclusion.

$$
\frac{\partial CO2e}{\partial Finclusion} = \beta_{1:4} + \beta_{6:9}\, Financial sustainability \tag{2}
$$

$$
ME_{mean} = \frac{\partial CO2e}{\partial Finclusion} = \beta_{1:4} + \beta_{6:9}\, \overline{financial\ sustainability}_{it}
$$

By applying the method of Brambor and Golder (2006), the standard error can be calculated as follows for each variable:

$$
\frac{\partial CO2e}{\partial Finclusion} = \sqrt{var(\beta_1) + Z^2 var(\beta_6) + 2Zcov(\beta_1\beta_6)}
$$

where $Z = \overline{financial\ sustainability}$

The t-statistics for marginal effect at the mean value of financial sustainability can be calculated as follows:

$$
t = \frac{\left(\beta_{1:4} + \beta_{6:9}\, \overline{financial\ sustainability_{it}}\right)}{\sigma_{\frac{\partial CO2e}{\partial Finclusion}}}
$$

$$
\sigma_{\frac{\partial CO2e}{\partial Finclusion}} = \frac{\left(\beta_1 + \beta_6\, \overline{financial\ sustainability_{it}}\right)}{\sqrt{var(\beta_1) + Z^2 var(\beta_6) + 2Zcov(\beta_1\beta_6)}}
$$

$$
ME_{min} = \frac{\partial CO2e}{\partial Finclusion} = \beta_{1:4} + \beta_{6:9} min(financial\ sustainability)_{it}
$$

$$
ME_{max} = \frac{\partial CO2e}{\partial Finclusion} = \beta_{1:4} + \beta_{6:9} max(financial\ sustainability)_{it}
$$

3.3 Quantile regression model

Unlike the OLS which is based on the conditional mean of the distribution, the quantile regression produces results for all the conditional quantiles of distribution for an outcome variable (Ramdani & Witteloostuijn, 2010). Quantile regression uses a conditional quantile function by splitting the conditional distribution function into segments, and it is appropriate for distribution with heteroskedasticity and the presence of outliers (Koenker & Bassett, 1978). The quantile estimation model is presented as follows:

$$Quant_q(y_{it}|x_{it}) = x_{it}\theta(_q) \tag{3}$$

where y_{it} is the dependent variable; CO_2 emissions at quantile q; and x_{it} is the vector of the independent variables.

The application of the fixed effects model, quantile regression and marginal effect analyses provides a comprehensive understanding of the relationship between financial inclusion, sustainability and carbon emission. First, the inclusion of fixed effects accounts for time-invariant unobserved heterogeneity at the individual level (Kansil, 2021). By incorporating individual fixed effects, we can account for any stable individual-level characteristics that may affect the outcome variable (CO_2 emission) but do not vary over time. This helps us to mitigate potential bias arising from unobserved individual heterogeneity, providing more reliable estimates of the relationship between financial inclusion, finance sustainability and carbon emission (Bell, 2015). Second, incorporating quantile regression provides a robust and comprehensive analysis of the relationship between financial inclusion, financial sustainability and carbon emission at different points of the conditional distribution. By estimating the effects at various quantiles (e.g. median, upper and lower quantiles), we can capture the heterogenous effects of financial inclusion and financial sustainability across different emission levels (Syed, Bhowmik, Adedoyin, Alola, & Khalid, 2022). This approach offers a more nuanced understanding of how these factors influence CO_2 emission, accounting for potential non-linear relationships and capturing effects that may be obscured in traditional mean-based regression models (Okada & Samreth, 2017). Third, complementing the fixed and quantile regression models, a marginal effect analysis allows us to examine the incremental impact of financial inclusion and finance sustainability on CO_2 emission associated with a unit change in financial inclusion and finance sustainability. This analysis helps us to evaluate the magnitude and direction of the effects (Okafor, Ede, Chijoke-Mgbame, Ohalehi, & Mgbame, 2021). Through their applications, this study can offer a critical examination of the complex dynamics between financial inclusion, financial sustainability and carbon emission, contributing to the existing body of literature.

4. Results and discussion

4.1 Results

The results of the fixed effects estimations are shown in Table 1. The baseline model (1) shows that account ownership has a negative and significant impact on carbon emissions. This suggests that individuals and entities with account ownership tend to have lower carbon emissions as account owners have better access to financial services, enabling them to invest in energy-efficient technologies or renewable energy sources. while ATM penetration rate, savings and credits have positive and significant coefficients, showing a positive impact on carbon emission. Higher ATM penetration, savings and credit availability may lead to increased economic activity, resulting in higher emissions from production processes and increased competition. The results are in line with Peterson & Ozili (2023). Also, financial institutions are not yet fully aligning their services with environmentally friendly practices, leading to an increase in carbon emissions. In addition, results also show that financial sustainability has significant negative coefficients across the five models, suggesting that sound financial sustainability reduces the total amount of CO_2 emissions. Therefore, financial institutions with strong financial sustainability may have policies that prioritize green

Variables	ln CO_2 *emissions* (1)	ln CO_2 *emissions* (2)	ln CO_2 *emissions* (3)	ln CO_2 *emissions* (4)	ln CO_2 *emissions* (5)
ln *accounts ownership*	−0.050***	−0.245***			
	(0.005)	(0.050)			
ln *ATM penetration rate*	0.200*		0.681***		
	(0.120)		(0.088)		
ln *savings*	0.151**			0.2672**	
	(0.066)			(0.066)	
ln *credits*	0.221***				0.175***
	(0.045)				(0.057)
ln *financial sustainability*	−0.434***	−0.070*	−0.126***	−0.246***	−0.091**
	(0.052)	(0.042)	(0.044)	(0.060)	(0.038)
The role of financial sustainability					
ln *accounts ownership* * ln *financial sustainability*		−0.012***			
		(0.027)			
ln *ATM penetration rate* * ln *financial sustainability*			−0.060*		
			(0.035)		
ln *savings* * in *financial sustainability*				−0.111***	
				(0.032)	
ln *credits* * ln *financial sustainability*					−0.080**
					(0.032)
GDP per capita	0.616***	0.756***	−0.196**	−0.014*	0.768***
	(0.113)	(0.096)	(0.079)	(0.139)	(0.149)
GDP square	−0.457***	−0.199*	−0.247***	−0.593***	−0.519***
	(0.109)	(0.120)	(0.080)	(0.124)	(0.098)
Energy consumption	0.843***	0.629***	0.407***	0.961***	1.096***
	(0.104)	(0.204)	(0.118)	(0.146)	(0.195)
Urbanisation	0.057***	0.026***	0.045***	0.055***	0.019***
	(0.003)	(0.004)	(0.003)	(0.004)	(0.007)
Political stability	−0.564***	−0.900***	−0.641***	−0.683***	−1.011***
	(0.048)	(0.055)	(0.052)	(0.060)	(0.071)
Trade openness	−0.849***	−0.399***	−0.982***	−0.764***	−0.784***
	(0.123)	(0.087)	(0.101)	(0.140)	(0.103)
Constant	5.034***	−4.593***	0.072	−1.125	−5.904***
	(0.729)	(1.403)	(0.766)	(0.821)	(1.325)
Observations	244	244	244	244	244
R-squared	0.942	0.954	0.947	0.882	0.941
Adj *R*2	0.937	0.949	0.938	0.873	0.931
F-stat	268.846	351.495	256.384	231.768	185.623
Country dummies	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes

Note(s): The data used in estimating the results from columns (1)-(5) were extracted from the World Development Indicators. In brackets, *t* values are reported. *, ** and *** are significant at 10%, 5% and 1% level, respectively

Source(s): Analysis provided by authors

Table 1. Financial inclusion, financial sustainability, and CO_2 emissions

lending and environmentally friendly capital investments (Bayram *et al.*, 2022). The interaction role of financial sustainability further reduces CO_2 emissions across the measures of financial inclusion. Therefore, the negative joint effect of higher accounts ownership and financial sustainability suggests that environment-friendly financial practices and services assist in the reduction of carbon emissions by aligning financing with sustainable projects and promoting responsible consumption and investment behaviour (Dou & Li, 2022).

Moreover, control variables like GDP, energy consumption, urbanization and trade openness are positively correlated with carbon emissions across the models. Higher GDP is associated with increased economic activity and energy demand. Further rapid industrialization and trade openness drive energy consumption, transportation needs and industrial activities. Also, political stability reduces carbon emissions. This suggests that more stable political environments may be better equipped to implement and enforce environmental regulations leading to reduction in carbon emission (Adebayo, 2022). Table 2 presents the marginal effect of financial sustainability using partial differentiation, while Table 3 presents the quantile regression results to establish the non-linearity effects of financial inclusion and financial sustainability on CO_2 emissions.

As shown in Table 2, the effect of measures of financial inclusion on CO_2 emissions is contingent on the level of financial sustainability. At the mean level of financial sustainability, with a 1% increase in accounts ownership savings and credits, the amount of CO_2 emissions will decrease by 0.01%, 0.08% and 0.11%. Furthermore, at the maximum level of financial sustainability, a 1% increase in accounts ownership, ATM penetration rate, savings and credits, the amount of CO_2 emissions will decrease by approximately 0.12%, 0.38%, 0.12% and 0.20, respectively. This finding supports Bodnar *et al.* (2018), that increasing public bank credits and long-term loans are successful in financing climate change mitigation goals.

Regarding the findings of quantile regression, this study demonstrates the outcomes at the 10th, 25th, 50th, 75th and 90th quantiles shown in Table 3. The results showed that account ownership appears to lower the amount of CO_2 emissions significantly in both lower and upper quantiles (q = 0.10, 0.25 and 0.90). This suggests that by increasing account ownership, the amount of CO_2 emissions is reduced in both high- and low-emission countries. Conversely, a higher ATM penetration rate appears to increase the total amount of CO_2 emissions significantly at extreme quantiles (q = 0.10 and q = 0.90), while saving positively impacts the emission across both lower and upper quantiles (q = 0.10, q = 0.50, q−0.75 and q = 0.90), though the strength of the relationship is heterogeneous among the quantiles. This implies that financial access (ATM penetration rates and level of saving) among less affluent countries may contribute to higher energy consumption and subsequent CO_2 emissions. Furthermore, at the lower and upper quantiles (q = 0.25, q = 0.50 and q = 0.90, an increase in credit availability is associated with a significant increment in carbon emissions. This implies that among the fewer-emission countries, higher levels of credit access lowers carbon emissions. In addition, financial sustainability negatively impacts carbon emissions, across

Table 2.
Marginal effects (using partial differentiation) of financial sustainability using the interaction model of Brambor and Golder (2006)
$ME = \left[\frac{\partial CO2emissions}{\partial financial\,inclusion} = \beta_1 + \beta_4\, financial\ sustainability_{it}\right]$

	The measures of financial inclusion			
	Accounts ownership	ATM penetration rate	Savings	Credits
$ME_{minimum}$	−0.002 (0.563)	0.060 (0.704) (0.077)	−0.055 (0.505)	−0.029
ME_{mean}	−0.006*** (0.056)	−0.162 (0.384)	−0.089*** (0.08) (0.002)	−0.118***
$ME_{maximum}$	−0.012*** (0.004)	−0.385*** (0.080)	−0.121*** (0.019)	−0.206*** (0.001)

Note(s): The data used in estimating the results from columns (1)-(4) were extracted from the World Development Indicators
***, ** and * denote significant at the 1, 5 and 10% levels, respectively. Values in the parentheses (.) indicate the standard errors. ME = marginal effect
Source(s): Analysis provided by author

Table 3. Quantile regression of CO_2 emissions, financial inclusion and financial sustainability $[Q_q(y_{it}|x_{it}) = x_{it}\theta(q)]$

Variables	0.10 (1)	0.25 (2)	0.50 (3)	0.75 (4)	0.90 (5)
Accounts ownership	−0.052***	−0.046***	−0.053***	−0.057***	−0.042***
	(−8.16)	(−5.55)	(−9.40)	(−7.85)	(−6.43)
ATM penetration	0.281*	0.155	0.174	0.189	0.0625*
	(2.04)	(0.86)	(1.42)	(1.21)	(0.44)
Savings	0.173*	0.155	0.152*	0.419***	0.218**
	(2.23)	(1.53)	(2.21)	(4.76)	(2.73)
Credits	−0.003	0.204**	0.280***	0.095	0.199***
	(−0.07)	(2.90)	(5.89)	(1.56)	(3.59)
Financial sustainability	−0.452***	−0.472***	−0.447***	−0.357***	−0.341***
	(−7.29)	(−5.81)	(−8.13)	(−5.06)	(−5.32)
GDP per capita	0.935***	0.663***	0.636***	0.588***	0.606***
	(7.07)	(3.83)	(5.42)	(3.91)	(4.43)
GDPsqr	−0.341*	−0.624***	−0.562***	−0.290	−0.569***
	(−2.57)	(−3.60)	(−4.78)	(−1.92)	(−4.16)
Energy consumption	0.631***	0.756***	0.720***	0.826***	0.748***
	(4.61)	(4.22)	(5.94)	(5.31)	(5.29)
Urbanization	0.066***	0.064***	0.055***	0.038***	0.032***
	(15.83)	(11.70)	(14.78)	(7.95)	(7.32)
Political stability	−0.525***	−0.602***	−0.584***	−0.578***	−0.648***
	(−8.40)	(−7.38)	(−10.55)	(−8.15)	(−10.04)
Trade openness	−0.644***	−0.795***	−0.757***	−0.797***	−0.691***
	(−4.89)	(−4.62)	(−6.49)	(−5.33)	(−5.08)
Constant	−6.355***	−5.246***	−4.346***	−4.574***	−2.850**
	(−6.09)	(−3.85)	(−4.70)	(−3.86)	(−2.64)
Observations	244	244	244	244	244

Note(s): The data used in estimating the results from columns (1)-(5) were extracted from the World Development Indicators

In brackets, *t* values are reported. *, ** and *** are significant at 10%, 5% and 1% levels, respectively. The equation is explained as follows. The elements of the parameter vector θ give the marginal effect of the corresponding explanatory variable. The notation $\theta(q)$ highlights the presence of a potentially different parameter vector at each respective quantile q of the distribution

Source(s): Analysis provided by author

all the quantiles, reflecting access to sustainable finance services and indicating the adoption of sustainable practices. Furthermore, GDP, energy consumption and urbanization appear to increase CO_2 emissions both at its extreme ends; at the lower quantile and highest quantile and across models, respectively (q = 0.10, q = 0.25, q = 0.50, q− = 0.75 and q = 0.90). In contrast to the aforementioned, political stability, GDP square and trade openness reduce carbon emission across all quantiles. It is worth noting that there is an increase in carbon emissions due to extensive usage of fossil fuel energy, industrialization and the race to a higher standard of living. In contrast, trade openness has a negative impact in lower quantiles (q = 0.10 and 0.25). It might be possible that trade openness and political stability can reduce emissions through technology transfer, improved environmental regulations and a stable political environment.

4.2 Robustness test results

To verify the robustness of basic regression results, we analyzed the impact of financial inclusion indicators (account ownership, atm penetration, savings and credits) on carbon emission during the Covid-19 pandemic. The results are presented in Supplementary Table S3. Firstly, across all four models, account ownership, ATM penetration, savings and credits exhibited a positive relationship with carbon emissions. The results in Table S3 demonstrated that account ownership, ATM penetration, savings and credits contribute to increased carbon emissions by 12%, 28%, 19% and 37%, respectively. This could be attributed to the fact that enhanced financial inclusion leads to greater economic activity, resulting in higher energy consumption and subsequently increased carbon emission (Du, Wu, Zhang, Lei, & Saeed, 2022). Secondly, we observed a negative and significant impact of financial sustainability and the Covid-19 dummy variable on carbon emissions across the models. This could be because the Covid-19 pandemic led to a more prolonged and widespread lockdown, resulting in a decrease in economic activity, agricultural, industrial, manufacturing and transportation activities, thus reducing carbon emissions (Ray, Singh, Singh, Acharya, & He, 2022). Also, the negative association with financial sustainability suggests that environmentally sustainable financial practices, such as investments in green technologies or renewable energy sources, may help mitigate carbon emissions. Furthermore, the interaction effect between the Covid-19 period and financial sustainability, as well as each financial indicator, also has a negative and significant relationship with carbon emissions. This indicates that financial activity disruptions and a decrease in money supply made investors hesitant to make new investments and also delayed ongoing capital investment projects due to the Covid-19 pandemic (Anser *et al.*, 2021); this, coupled with a focus on sustainable financial practices, led to a decrease in carbon emission. Moreover, the control variables are consistent with basic results, further validating the robustness of our findings.

4.3 Discussion

Developing economies face a significant challenge in mitigating climate risks, as these nations possess the potential for rapid economic development that may inadvertently harm the environment. In this regard, our results of financial inclusion accelerate carbon emissions due to financial inclusion. This indicates that the conventional policies intended to promote financial inclusion in these nations are not aligned with their commitment to ecological welfare objectives. The results of the positive relationship between financial inclusion and carbon emission can be attributed to the fact that developing nations can be linked to an increase in energy demand from both the production and consumption side. The plausible reason for this is that the availability of ATMs and bank branches enhances access to financial services and involves the construction and operation of physical infrastructure, resulting in higher energy usage. In addition, the energy associated with operating ATMs' electricity usage and maintenance, increased savings and access to credits enables individuals and businesses to pursue personal and economic goals by spending on carbon-intensive goods and services, industrial expansion and infrastructure. Given the heavy reliance on fossil fuels in developing countries, it is anticipated that the rise in energy demand caused by financial inclusion will lead to an increase in carbon dioxide emissions. In the same vein, as the economy experiences growth and its domestic output level increases, it induces a corresponding surge in energy demands, ultimately leading to elevated levels of carbon emission (Liu, Sinha, Destek, Alharthi, & Zafar, 2022).

On the other hand, the finding of a negative nexus between financial sustainability and carbon emission can be explained by encouraging the development and implementation of financing renewable energy projects, such as solar and wind power, which reduce reliance on fossil fuels and consequently reduce carbon dioxide (CO_2) emissions. Besides green financing, it can direct capital toward low-carbon and sustainable initiatives, thereby contributing further to the reduction of greenhouse gas emissions. In addition, financial sustainability can incorporate climate risk assessments, allowing for the identification and mitigation of climate-related investment risks. In addition, it assists businesses in adopting sustainable practices, integrating environmental considerations into strategies and promoting ecofriendly supply chains, which ultimately result in emission reductions throughout the entire value chain. Furthermore, the strengthening of climate change by international and domestic regulatory frameworks like the Paris Agreement (2015) and the African Ministerial Conference on the Environment (AMCE) (1985) has strengthened the call to the financial community to foster financial sustainability. Thereby, there is a pressure on banks to encourage credit financing for renewable energy projects, green financing energy initiatives and promoting sustainable agricultural practices.

The other key findings confirm that economic growth can exacerbate carbon dioxide emissions. This observation is especially pertinent for African nations that are experiencing economic growth and rely primarily on non-renewable energy sources. In these nations, economic activities undertaken are creating a trade-off between pursuing increased economic growth and grappling with intensified environmental challenges. Linking it with the environmental Kuznets curve (EKC) theory suggests that the selected African nations have attained a critical threshold of economic growth, indicating that it is time to adopt and implement policies aimed at reducing CO_2 emissions. Furthermore, another finding of this study confirms that energy consumption and urbanization positively impact carbon emissions in African countries. The scenario can be attributed to the increased combustion of energy (fossil fuels), which contributes to the overall increase in emissions by releasing carbon dioxide into the atmosphere (Peter & Ndubuisi, 2022). Furthermore, urbanization leads to an increase in emissions since urbanization fuels the demand for fossil energy. Besides, it induces waste generation and deforestation due to urban expansion. These findings are in line with Erdoğan *et al.*'s (2022) study on African countries.

Another key finding derived from this study is regarding political stability and trade openness being linked with the reduction of carbon emissions. Political stability permits the establishment of regulatory frameworks that incentivize the adoption of sustainable practices and renewable energy sources. Therefore, there is a greater likelihood of implementing and maintaining consistent environmental policies and practices in nations with stable political systems, supporting past studies in the African context (e.g. Abid, 2016). Lastly, the scenario in which trade openness reduces can be attributed to the fact that trade openness increases access to advanced technologies and knowledge from more environmentally advanced nations. This is consistent with the trade-related "pollution halo hypothesis" (Cole, Elliott, & Fredriksson, 2006), which posits that trade openness has a positive environmental effect because countries with stricter environmental regulations tend to specialize in cleaner industries and export environmentally friendly goods and services.

5. Conclusion and policy implications

Rapid economic expansion in African countries accelerates CO_2 emissions, creating a challenging trade-off between economic benefits and environmental costs. This trade-off is exacerbated by the widespread use of fossil fuels in many African countries, which makes it difficult to accomplish economic expansion without causing environmental degradation. Despite the advocation of the United Nations Framework Convention on Climate change in the reduction of CO_2 emissions, the rising level of financial inclusion and financial development has contributed to increasing CO_2 emissions. Under the given circumstances, it is of paramount importance to identify effective strategies to mitigate the carbon emissions faced by African countries. Against this backdrop, the primary objective of this research was to examine the impact of financial inclusion and carbon dioxide (CO_2) emissions with financial sustainability as a moderator in 17 African economies. Several control variables were introduced into the study to guarantee accurate and dependable results. These control variables included energy consumption, GDP growth, GDP per capita, trade liberalization, urbanization and political stability. The effect of financial inclusion on CO_2 emissions in the African context was analysed using panel fixed effect and quantile regression.

The econometric results suggest that financial inclusion does not significantly contribute to emission reduction in African countries. However, the results reveal that financial sustainability moderates the association between financial inclusion and CO_2 emissions. As evidenced by the findings of this study, financial sustainability does not only reduce CO_2 emissions, but it further reduces the positive effects of account ownership, atm penetration rate and credits on CO_2 emissions. Therefore, financial sustainability measured as bank credit to bank deposits and liquid assets to deposits and short-term funding can mitigate carbon emissions through initiatives like expanding access to green financing, renewable energy projects and factoring in climate risk when determining loan terms reduce the carbon emission. In addition, economic growth, energy consumption and urbanization have a strong positive correlation with CO_2 emissions. On the other hand, it was discovered that political stability and trade openness have a negative relationship with CO_2 emissions.

Based on these important findings, we propose a series of crucial carbon emission mitigation policies. Firstly, to effectively address the environmental challenges associated with promoting financial inclusion, it is essential for African economies to simultaneously promote financial inclusivity and environmental sustainability. These nations must identify the financial risks which are pertinent to the increase in carbon emissions and take proactive steps to align their financial services with sustainable practices. In addition, the implementation of green financial initiatives that provide incentives for investments in renewable energy, energy efficiency and sustainable technologies should be investigated to mitigate the negative environmental effects of promoting financial inclusion. Secondly, increasing the sources of financial sustainability can meet the financing of carbon storage, carbon capture and alternative renewable energy that is cost-efficient and results in the reduction of CO_2 emissions. The government must assess the degree of financial inclusion practices and how each phase and every activity affect CO_2 emission. This will help to plan adequately in the distribution of alternative energy sources into different locations to meet households' and corporates' energy requirements and needs. For instance, hot and sunny locations may be operated using solar-based ATMs to reduce the CO_2 emissions generated by ATMs. This supports that a solar-based PV power generation system is expected to reduce CO_2 emissions between 69-100 million tons by 2030 (Hosenuzzaman *et al.*, 2015). Thirdly, incorporating climate risk assessments into financial decision-making processes can assist in identifying and managing environmental hazards associated with investments. In addition, capacity-building programs should be implemented to improve financial literacy and environmental awareness, thereby empowering individuals and businesses to make sustainable decisions. Moreover, strict regulatory frameworks should be created and enforced to promote environmentally responsible lending practices and support sustainable initiatives. Fourthly, African economies must swiftly switch to using more renewable energy sources and less fossil fuels to power their economies. To make this change, substantial funds must be invested in R&D to improve renewable electricity generation technology. Fifthly, African countries should encourage ecologically friendly economic growth that does not trade environmental well-being for greater economic growth. Sixthly, urban planning sustainability should be prioritized for mitigating urbanization-led carbon emissions in African countries. Furthermore, a significant aspect of this approach involves that meeting the escalating urban energy demand through the utilization of clean energy resources (solar, wind and hydropower) can diminish their dependence on fossil fuels and effectively mitigate associated carbon emissions.

Lastly, our study has a practical impact on environmental sustainability in Africa through sustainable cash notes. The use of sustainable cotton-fiber paper in the production of banknotes can reduce the negative environmental impacts of cash. Finland, the Netherlands and other members of the Joint Euro Tender (JET) across eight Euro countries are adopting the use of sustainable cotton paper via the application of a protective varnish layer to enhance the durability of banknotes (Bank of Finland, 2020).

References

Abbasi, F., & Riaz, K. (2016). CO_2 emissions and financial development in an emerging economy: An augmented VAR approach. *Energy Policy*, *90*, 102–114. doi: 10.1016/j.enpol.2015.12.017.

Abid, M. (2016). Impact of economic, financial, and institutional factors on CO2 emissions: Evidence from Sub-Saharan Africa economies. *Utilities Policy*, *41*, 85–94. doi: 10.1016/j.jup.2016.06.009.

Adebayo, T. S. (2022). Renewable energy consumption and environmental sustainability in Canada: Does political stability make a difference? *Environmental Science and Pollution Research*, *29*(40), 61307–61322.

Anser, M. K., Khan, M. A., Zaman, K., Nassani, A. A., Askar, S. E., Abro, M. M. Q., & Kabbani, A. (2021). Financial development during COVID-19 pandemic: The role of coronavirus testing and functional labs. *Financial Innovation*, *7*, 1–13.

Baltagi, B. H., & Giles, M. D. (1998). Panel data methods. *Statistics Textbooks And Monographs*, *155*, 291–324, Bank of Finland (2020).

Bank of Finland (2020). Environmental impact of cash in Finland. Available from: https://www.suomenpankki.fi/en/bank-of-finland/sustainability/environmental-impact-of-cash-in-Finland/ (accessed 29 July 2020).

Baulch, B., Do, T. D., & Le, T. H. (2018). Constraints to the uptake of solar home systems in Ho Chi Minh City and some proposals for improvement. *Renewable Energy*, *118*, 245–256.

Bayram, O., Talay, I., & Feridun, M. (2022). Can fintech promote sustainable finance? Policy lessons from the case of Turkey. *Sustainability (Switzerland)*, *14*(19). doi: 10.3390/su141912414.

Bell, A. (2015). Explaining fixed effects: Random effects modeling of time-series cross-sectional and panel data. *Political Science Research and Methods*, *3*(1), 133–153. doi: 10.1017/psrm.2014.7.

Bergman, M., Guibourg, G., & Segendorf, B. (2008). Card and cash payments from a social perspective. *Sveriges Riksbank Economic Review*, *2*, 42–59.

Bodnar, P., Ott, C., Edwards, R., Hoch, S., McGlynn, E. F., & Wagner, G. (2018). Underwriting 1.5°C: Competitive approaches to financing accelerated climate change mitigation. *Climate Policy*, *18*(3), 368–382. doi: 10.1080/14693062.2017.1389687.

Bouma, J. J., Jeucken, M., & Klinkers, L. (Eds) (2017). In *Sustainable banking: The greening of finance*. Routledge.

Bouwer, L. M., & Aerts, J. C. (2006). Financing climate change adaptation. *Disasters*, *30*(1), 49–63. doi: 10.1111/j.1467-9523.2006.00306.x.

Brambor, C., & Golder (2006). Understanding interaction models: Improving empirical analysis. *Political Analysis*, *14*(1), 63–82. doi: 10.1093/pan/mpi014.

Cao, L. (2023). How green finance reduces CO2 emissions for green economic recovery: Empirical evidence from E7 economies. *Environmental Science and Pollution Research*, *30*(2), 3307–3320. doi: 10.1007/s11356-022-22365-6.

Charfeddine, L., & Kahia, M. (2019). Impact of renewable energy consumption and financial development on CO_2 emissions and economic growth in the MENA region: A panel vector autoregressive (PVAR) analysis. *Renewable Energy*, *139*, 198–213. doi: 10.1016/j.renene.2019.01.010.

Cole, M. A., Elliott, R. J., & Fredriksson, P. G. (2006). Endogenous pollution havens: Does FDI influence environmental regulations?. *Scandinavian Journal of Economics*, *108*(1), 157–178. doi: 10.1111/j.1467-9442.2006.00439.x.

Currency Research (2017). Cash in circulation continues to grow by 5% annually (Online). Available from: https://www.cashmatters.org/blog/cash-circulation-growing-5-annually/ (accessed 28 July 2020).

Dou, D., & Li, L. (2022). Does sustainable financial inclusion and energy efficiency ensure green environment? Evidence from B.R.I.C.S. Countries. *Economic Research-Ekonomska Istrazivanja*, *35*(1), 5599–5614. doi: 10.1080/1331677X.2022.2032785.

Du, Q., Wu, N., Zhang, F., Lei, Y., & Saeed, A. (2022). Impact of financial inclusion and human capital on environmental quality: Evidence from emerging economies. *Environmental Science and Pollution Research*, *29*(22), 33033–33045. doi: 10.1007/s11356-021-17945-x.

Erdoğan, S., Taiwo, S., Altuntaş, M., & Victor, F. (2022). Synthesizing urbanization and carbon emissions in Africa: How viable is environmental sustainability amid the quest for economic growth in a globalized world. *Environmental Science and Pollution Research*, *29*(16), 24348–24361. doi: 10.1007/s11356-022-18829-4.

Esselink, H., & Hernández, L. (2017). *The use of cash by households in the euro area*. European Central Bank's Occasional Paper Series (No. 201).

Gebrehiwot, K. G., & Makina, D. (2019). Macroeconomic determinants of financial inclusion: Evidence using dynamic panel data analysis. In *Extending financial inclusion in Africa* (pp. 167–191). Academic Press.

Guo, M., Hu, Y., & Yu, J. (2019). The role of financial development in the process of climate change: Evidence from different panel models in China. *Atmospheric Pollution Research*, *10*(5), 1375–1382. doi: 10.1016/j.apr.2019.03.006.

Hanegraaf, R., Larçin, A., Jonker, N., Mandley, S., & Miedema, J. (2020). Life cycle assessment of cash payments in The Netherlands. *The International Journal of Life Cycle Assessment*, *25*(1), 120–140. doi: 10.1007/s11367-019-01637-3.

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *The Stata Journal*, *7*(3), 281–312.

Hosenuzzaman, M., Rahim, N. A., Selvaraj, J., Hasanuzzaman, M., Malek, A. A., & Nahar, A. (2015). Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. *Renewable and Sustainable Energy Reviews*, *41*, 284–297. doi: 10.1016/j.rser.2014.08.046.

Hussain, S., Akbar, M., Gul, R., Shahzad, S. J. H., & Naifar, N. (2023). Relationship between financial inclusion and carbon emissions: International evidence. *Heliyon*, *9*(6), e16472. doi: 10.1016/j.heliyon.2023.e16472.

Jebli, M. B., & Hakimi, A. (2023). How do financial inclusion and renewable energy collaborate with environmental quality? Evidence for top ten countries in technological advancement. *Environmental Science and Pollution Research*, *30*(11), 31755–31767. doi:10.1007/s11356-022-24430-6.

Kansil, R. (2021). Relation between foreign ownership and firm value – fixed-effect panel threshold regression analysis. *World Journal of Science, Technology and Sustainable, Development*, *18*(2), 109–129. doi:10.1108/WJSTSD-11-2020-0095.

Khan, S., Peng, Z., & Li, Y. (2019). Energy consumption, environmental degradation, economic growth and financial development in globe: Dynamic simultaneous equations panel analysis. *Energy Reports*, *5*, 1089–1102. doi: 10.1016/j.egyr.2019.08.004.

Kirikkaleli, D., Adebayo, T. S., & Güngör, H. (2021). Consumption-based carbon emissions , renewable energy consumption , financial development and economic growth in Chile, December. doi: 10.1002/bse.2945.

Koenker, R., & Bassett, G. Jr (1978). Regression quantiles. *Econometrica, Journal of Econometric Society*, *46*(1), 33–50. Available from: http://www.jstor.com/stable/1913643

Le, T. H., Chuc, A. T., & Taghizadeh-Hesary, F. (2019). Financial inclusion and its impact on financial efficiency and sustainability: Empirical evidence from Asia. *Borsa Istanbul Review*, *19*(4), 310–322. doi: 10.1016/j.bir.2019.07.002.

Le, T. H., Le, H. C., & Taghizadeh-Hesary, F. (2020). Does financial inclusion impact CO2 emissions? Evidence from Asia. *Finance Research Letters*, *34*, 101451.

Li, G., & Wei, W. (2021). Financial development, openness, innovation, carbon emissions, and economic growth in China. *Energy Economics*, *97*, 105194. doi: 10.1016/j.eneco.2021.105194.

Liu, H., Sinha, A., Destek, M. A., Alharthi, M., & Zafar, M. W. (2022). Moving toward sustainable development of sub-Saharan African countries: Investigating the effect of financial inclusion on environmental quality. *Sustainable Development*, *30*(6), 2015.

McCook, H. (2014). An order-of-magnitude estimate of the relative sustainability of the Bitcoin network. Available from: https://www.academia.edu/7666373/An_Order-of-Magnitude_Estimate_of_the_Relative_Sustainability_of_the_Bitcoin_ Network_-_2nd_Edition (accessed 18 May 2020).

Monasterolo, I., & Raberto, M. (2019). The impact of phasing out fossil fuel subsidies on the low-carbon transition. *Energy Policy*, *124*, 355–370. doi: 10.1016/j.enpol.2018.08.051.

Nasir, M. A., Huynh, T. L. D., & Tram, H. T. X. (2019). Role of financial development, economic growth and foreign direct investment in driving climate change: A case of emerging ASEAN. *Journal of Environmental Management*, *242*, 131–141. doi: 10.1016/j.jenvman.2019.03.112.

Nwani, C., & Omoke, P. C. (2020). Does bank credit to the private sector promote low-carbon development in Brazil? An extended STIRPAT analysis using dynamic ARDL simulations. *Environmental Science and Pollution Research*, *27*(25). doi: 10.1007/s11356-020-09415-7.

Okada, K., & Samreth, S. (2017). Corruption and natural resource rents: Evidence from quantile regression. *Applied Economics Letters*, *24*(20), 1490–1493. doi: 10.1080/13504851.2017.1287849.

Okafor, G., Ede, O., Chijoke-Mgbame, A. M., Ohalehi, P., & Mgbame, O. C. (2021). Ownership structure, corruption, and capital investment: Evidence from firms in selected Sub-Saharan African countries. *Thunderbird International Business Review*, *63*(4), 403–420. doi: 10.1002/tie.22203.

Ouma, S. A., Odongo, T. M., & Were, M. (2017). Mobile financial services and financial inclusion: Is it a boon for savings mobilization?. *Review of Development Finance*, *7*(1), 29–35. doi: 10.1016/j.rdf.2017.01.001.

Peter, E., & Ndubuisi, C. (2022). Heterogeneous analysis of energy consumption, financial development, and pollution in Africa: The relevance of regulatory quality. *Utilities Policy*, *74*, 101328, November 2021. doi: 10.1016/j.jup.2021.101328.

Peterson, K., & Ozili, P. K. (2023). Financial inclusion and environmental sustainability, 116586.

Raheem, I. D., Tiwari, A. K., & Balsalobre-Lorente, D. (2020). The role of ICT and financial development in CO_2 emissions and economic growth. *Environmental Science and Pollution Research*, *27*(2), 1912–1922. doi: 10.1007/s11356-019-06590-0.

Ramdani, D., & Witteloostuijn, A. V. (2010). The impact of board independence and CEO duality on firm performance: A quantile regression analysis for Indonesia, Malaysia, South Korea and Thailand. *British Journal of Management*, *21*(3), 607–627. doi: 10.1111/j.1467-8551.2010.00708.x.

Ray, R. L., Singh, V. P., Singh, S. K., Acharya, B. S., & He, Y. (2022). What is the impact of COVID-19 pandemic on global carbon emissions? *Science of The Total Environment*, *816*, 151503. doi: 10.1016/j.scitotenv.2021.151503.

Schmidheiny, K., & Basel, U. (2011). Panel data: Fixed and random effects. *Short Guides to Microeconometrics*, *7*(1), 2–7.

Shahbaz, M., Haouas, I., Sohag, K., & Ozturk, I. (2020). The financial development-environmental degradation nexus in the United Arab Emirates: The importance of growth, globalization and structural breaks. *Environmental Science and Pollution Research*, *27*(10685-10699), 1–15. doi: 10.1007/s11356-019-07085-8.

Shoaib, H. M., Rafique, M. Z., Nadeem, A. M., & Huang, S. (2020). Impact of financial development on CO_2 emissions: A comparative analysis of developing countries (D8) and developed countries (G 8). *Environmental Science and Pollution Research*, *27*(12461-12475), 1–15. doi: 10.1007/s11356-019-06680-z.

Syed, Q. R., Bhowmik, R., Adedoyin, F. F., Alola, A. A., & Khalid, N. (2022). Do economic policy uncertainty and geopolitical risk surge CO2 emissions? New insights from panel quantile regression approach. *Environmental Science and Pollution Research*, *29*(19), 27845–27861.

Tian, Y., & Li, L. (2022). Impact of financial inclusion and globalization on environmental quality: Evidence from G20 economies. *Environmental Science and Pollution Research*, *29*(40), 61265–61276. doi: 10.1007/s11356-022-19618-9.

Tsimisaraka, R. S. M., Xiang, L., Andrianarivo, A. R. N. A., Josoa, E. Z., Khan, N., Hanif, M. S., . . . Limongi, R. (2023). Impact of financial inclusion, globalization, renewable energy, ICT, and economic growth on CO_2 emission in OBOR countries. *Sustainability (Switzerland)*, *15*(8). doi: 10.3390/su15086534.

Udi, J., Bekun, F. V., & Adedoyin, F. F. (2020). Modeling the nexus between coal consumption, FDI inflow and economic expansion: Does industrialization matter in South Africa? *Environmental Science and Pollution Research*, *27*(10553-10564), 1–12. doi: 10.1007/s11356-020-07691-x.

United Nations (2020). UN: Cash helps fight Covid in developing world.

Wan, J., Pu, Z., & Tavera, C. (2023). The impact of digital finance on pollutants emission: Evidence from Chinese cities. *Environmental Science and Pollution Research*, *30*(15), 42923–42942. doi: 10.1007/s11356-021-18465-4.

Wang, R., Mirza, N., Vasbieva, D. G., Abbas, Q., & Xiong, D. (2020). The nexus of carbon emissions, financial development, renewable energy consumption, and technological innovation: What should be the priorities in light of COP 21 Agreements?. *Journal of Environmental Management*, *271*, 111027. doi: 10.1016/j.jenvman.2020.111027.

Wettstein, F., Lieb, B., & Lieb, H. (2000). Life cycle assessment (LCA) of Swiss banknotes. *Quarterly Bulletin*, *3*, 1–14.

World Bank (2018). Financial inclusion. Available from: https://www.worldbank.org/en/topic/financialinclusion/overview#1 (accessed 16 July 2020).

Zafar, M. W., Zaidi, S. A. H., Sinha, A., Gedikli, A., & Hou, F. (2019). The role of stock market and banking sector development, and renewable energy consumption in carbon emissions: Insights from G-7 and N-11 countries. *Resources Policy*, *62*, 427–436. doi: 10.1016/j.resourpol.2019.05.003.

Zaidi, S. A. H., Zafar, M. W., Shahbaz, M., & Hou, F. (2019). Dynamic linkages between globalization, financial development and carbon emissions: Evidence from Asia Pacific Economic Cooperation countries. *Journal of Cleaner Production*, *228*, 533–543. doi: 10.1016/j.jclepro.2019.04.210.

Zhang, B., Yang, Y., & Bi, J. (2011). Tracking the implementation of green credit policy in China: Top-down perspective and bottom-up reform. *Journal of Environmental Management*, *92*(4), 1321–1327. doi: 10.1016/j.jenvman.2010.12.019.

Zins, A., & Weill, L. (2016). The determinants of financial inclusion in Africa. *Review of Development Finance*, *6*(1), 46–57. doi: 10.1016/j.rdf.2016.05.001.

Further reading

Su, C. W., Umar, M., Kirikkaleli, D., Awosusi, A. A., & Altuntaş, M. (2023). Testing the asymmetric effect of financial stability towards carbon neutrality target: The case of Iceland and global comparison. *Gondwana Research*, *116*(April), 125–135. doi: 10.1016/j.gr.2022.12.014.

The World Bank World development indicators. Washington. DC. Available from: http://data.worldbank.org/data-catalog/world-development-indicators (accessed 15 February 2020).

Supplementary material

Table S1.
Currency-CO_2 emissions impact (mean 2004-2014)

Country	CO_2 from automated teller machines (per 100,000 adults)	CO_2 emissions from bank branches (per 100,000 adults)	CO_2 from ATMs as a percentage of total CO_2 emissions (per 100,000 adults)	CO_2 from bank branches as a percentage of total CO_2 emissions (per 100,000 adults)
Algeria	6.148	3234.430	0.005	2.800
Angola	11.927	3864.937	0.040	13.367
Benin	2.185	1594.446	0.039	33.840
Botswana	33.239	5061.952	0.743	113.583
Burkina Faso	1.425	1162.699	0.055	60.060
Burundi	0.693	1415.006	0.245	616.607
Cabo Verde	46.466	17235.572	9.236	3482.817
Cameroon	2.264	889.699	0.037	15.591
Central African Republic	0.586	423.697	0.206	156.033
Chad	0.465	366.389	0.079	68.512
Comoros	3.741	937.660	2.577	661.369
Congo, Dem. Rep	0.422	356.893	0.014	17.133
Congo, Rep	2.603	1194.068	0.118	60.877
Cote d'Ivoire	3.000	1955.785	0.033	24.641
Djibouti	3.560	2324.126	0.657	457.520
Egypt, Arab Rep	9.805	2751.327	0.005	1.418
Equatorial Guinea	3.705	2073.537	0.072	41.518
Eswatini	28.955	4202.985	2.651	390.681
Ethiopia	0.164	722.355	0.002	10.782
Gabon	9.023	2784.874	0.192	58.926
Ghana	4.495	3019.457	0.040	30.359
Guinea	0.965	833.868	0.041	36.122
Guinea-Bissau	1.572	935.772	0.611	379.938
Kenya	8.492	2628.639	0.071	23.064
Lesotho	9.069	1818.612	0.399	81.270
Liberia	1.258	1453.830	0.163	183.517
Libya	4.769	6868.312	0.009	13.000
Madagascar	1.662	903.854	0.075	42.318
Malawi	3.590	1306.796	0.328	121.929
Mali	2.144	2327.346	0.198	230.126
Mauritania	2.742	2225.614	0.104	95.510
Mauritius	52.808	13014.646	1.404	347.199
Morocco	24.072	11108.599	0.044	20.363
Mozambique	6.839	1902.427	0.226	67.122
Namibia	41.897	7806.109	1.371	283.683
Niger	0.599	571.801	0.035	48.466
Nigeria	11.076	3535.537	0.012	3.734
Rwanda	2.659	2385.504	0.364	361.528
Sao Tome and Principe	10.105	11468.321	9.100	11117.126
Senegal	2.862	2398.539	0.035	37.380
Seychelles	60.697	29017.738	12.043	5626.192
Sierra Leone	0.221	1030.261	0.029	141.190
Somalia	0.000	0.000	0.000	0.000
South Africa	60.865	5410.695	0.013	1.152

(*continued*)

Country	CO_2 from automated teller machines (per 100,000 adults)	CO_2 emissions from bank branches (per 100,000 adults)	CO_2 from ATMs as a percentage of total CO_2 emissions (per 100,000 adults)	CO_2 from bank branches as a percentage of total CO_2 emissions (per 100,000 adults)
Sudan	3.052	1745.772	0.020	12.390
Tanzania	3.692	1067.223	0.043	14.066
Togo	1.825	2165.718	0.071	102.281
Tunisia	22.799	9727.890	0.088	38.146
Uganda	4.116	1354.044	0.115	38.698
Zambia	7.177	2385.996	0.237	87.331
Zimbabwe	6.785	4327.591	0.080	46.906

Note(s): We computed the average CO_2 emissions from automated teller machines and bank branches using the methodology of McCook (2014). McCook (2014) found that 600,000 bank branches emit 383.1 million tons of CO_2 emissions per year. This amounts to an average of 638.5 tons emitted per branch in a year. We then multiply 638.5 by the number of bank branches in each of the countries annually. About 3.2 million CO_2 emissions are emitted from 2,394,700 ATMs in the world annually (McCook, 2014). By calculation, each ATM emits 1.336 tons of CO_2 emissions per year. We adopt the same process as in bank branches

Source(s): Analysis provided by author

Table S1.

Variables	Measurement	Source
CO_2 emission	The total carbon dioxide emission from the consumption of energy measured in million metric tons	European Union Publication on CO_2 and GHG emissions, WDI
Financial inclusion	Accounts ownership (automated teller machines per 100,000 adults)	WDI
	ATM penetration Rate (bank branches per 100,000 adults)	WDI
	Savings (deposit accounts with commercial banks per 1000 adults)	WDI
	Credits (borrowers from commercial banks per 1000 adults)	WDI
Financial sustainability	Bank credit to bank deposits (%)	WDI
	Liquid assets to deposits and short-term funding (%)	WDI
GDP	GDP per capita (constant 2015 US$)	WDI
GDP square	Square of GDP per capita (constant 2015 US$)	
Energy consumption	Energy use (kg of oil equivalent per capita)	WDI
Urban population	The population is measured in millions of persons to indicate urbanization	WDI
Trade openness	(Exports + imports (BoP, current US$)/GDP	WDI
Political stability	Perceptions of political instability, politically motivated violence, including terrorism	WDI

Note(s): This table presents variables used in this paper and sources of raw data. *WDI is World Development Indicator

Source(s): Table provided by author

Table S2.
Description of variables

Variables	CO_2 emissions (1)	CO_2 emissions (2)	CO_2 emissions (3)	CO_2 emissions (4)
Accounts ownership	0.116*			
	(.065)			
ATM penetration		.0276**		
		(0.109)		
Savings			0.189***	
			(0.000)	
Credit				0.366***
				(0.038)
Financial sustainability	−0.203***	−0.177***	−0.096**	−0.268***
	(0.074)	(0.052)	(0.041)	(0.035)
Covid. dummy	−0.230*	−0.271**	−0.1453*	−0.297***
	(0.132)	(0.113)	(0.086)	(0.098)
The role of Covid-19				
Account ownership Covid*Sustainability*	−0.063*			
	(0.037)			
ATM penetration Covid*sustainability*		−0.069**		
		(0.033)		
Savings Covid* sustainability*			−0.025**	
			(0.010)	
Credits Covid* sustainability*				−0.036**
				(0.040)
GDPPC	0.065	0.563***	0.734***	0.270***
	(0.161)	(0.161)	(0.175)	(0.133)
GDP square	−0.664***	−1.595***	−1.787***	−1.360***
	(0.144)	(0.209)	(0.166)	(0.108)
Energy consumption	0.968***	2.091***	1.068***	0.011
	(0.217)	(0.234)	(0.169)	(0.167)
Urbanization	0.036***	0.026***	−0.004	0.036***
	(0.005)	(0.005)	(0.006)	(0.003)
Trade openness	−0.863***	−0.803***	−0.632***	−0.602***
FDI	0.256**			
	(0.038)			
Political stability	−0.404***	−0.629***	−0.536***	−0.713***
	(0.086)	(0.072)	(0.043)	(0.052)
Constant	−4.885***	−10.70***	−4.132***	4.446***
	(1.246)	(2.118)	(1.397)	(1.172)
Observations	244	244	244	244
R-squared	0.900	0.946	0.970	0.952
Adj R^2	0.891	0.941	0.967	0.948
F-stat	372.421	301.481	505.280	559.232
Country dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes

Note(s): The data used in estimating the results from columns (1)-(4) were extracted from the World Development Indicators. In brackets, *t* values are reported. *, ** and *** are significant at 10%, 5%, and 1% level, respectively

Source(s): Analysis provided by author

Table S3. Financial inclusion, Covid-19 and CO_2 emissions

Corresponding author

Shahida Rasheed can be contacted at: Shahida.Scholar@kashmiruniversity.net