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Balancing finance and sustainability: The impact of financial access on carbon emissions through innovation and entrepreneurship in a global study

Eric B. Yiadom [a,*], Paapa N. Indome [a], John K.M. Mawutor [b], George Domfe [c]

[a] Banking and Finance Department, University of Professional Studies, Accra, Ghana
[b] Accounting Department, University of Professional Studies, Accra, Ghana
[c] Centre for Social Policy Studies, University of Ghana, Ghana

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ABSTRACT

This study examines the interplay between financial access, innovation, entrepreneurship, and carbon emissions using a dataset of 149 countries over 24 years (2000–2023). Employing two-stage least squares (2SLS) techniques to address endogeneity, the findings reveal that financial access significantly boosts innovation and entrepreneurship, which are key drivers of economic growth. However, financial access may also increase carbon emissions if not aligned with sustainable practices. Innovation reduces emissions by fostering environmentally friendly technologies, while entrepreneurship initially contributes to emissions but can mitigate this effect when supported by sustainable financial practices. The study highlights the importance of financial policies that promote green innovation and sustainable entrepreneurship, offering actionable insights for policymakers to achieve economic growth while addressing global carbon emissions.

1. Introduction

The interplay between financial access, innovation, entrepreneurship, and carbon emissions has become a focal point in addressing global challenges like climate change and sustainable development. Industrialization, while pivotal for economic growth, has been identified as a major contributor to carbon emissions and global warming (Yiadom et al., 2023a; Yiadom et al., 2022; Dong et al., 2019). Although deindustrialization is not a viable solution, moderating the environmental impact of industrial activities through innovation and entrepreneurship has emerged as a key strategy. This study investigates how financial access enhances innovation and entrepreneurship to mitigate carbon emissions, aiming to provide actionable insights for policymakers and stakeholders globally.

While numerous studies have examined the relationship between financial development and carbon emissions, theoretical gaps persist. For instance, the existing literature often overlooks the nuanced role of financial access in shaping sustainable entrepreneurship and innovation. Studies like those by Li and Wei (2021) emphasize the importance of financial development in supporting innovations to curb carbon emissions but fail to explore the complexities of how unequal financial access hinders or facilitates this process. Moreover, conflicting findings exist regarding the relationship between financial access and sustainability. Jiang and Ma (2019) found that financial development can lead to increased carbon emissions in developing economies, whereas Mushtaq et al. (2022) argue that financial access fosters innovation that reduces emissions. This study addresses these gaps by exploring the

* Corresponding author.
E-mail address: boachie.eric@upsamail.edu.gh (E.B. Yiadom).

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bidirectional relationships between financial access, innovation, and carbon emissions, as well as the moderating role of financial access in enhancing sustainable entrepreneurship.

This research distinguishes itself by providing a global perspective on the bidirectional relationship between financial access and innovation while examining their collective impact on carbon emissions. Unlike previous studies that primarily focus on either financial access or carbon emissions in isolation, this study integrates these variables within a comprehensive framework. Additionally, it examines how financial access moderates the relationship between innovation and entrepreneurship, highlighting its critical role in promoting green technologies. By employing a dataset from 149 countries over 24 years (2000–2023) and using two-stage least squares (2SLS) estimation techniques, this study offers a more nuanced analysis, addressing endogeneity concerns and ensuring robust results.

The study's global scope reflects the urgent need for universally applicable insights into sustainable development. Disparities in financial access, as highlighted by the World Bank Global Findex Database (2021), remain a significant barrier to achieving global sustainability goals. For example, while 69% of adults globally have bank accounts, access remains uneven, particularly in sub-Saharan Africa and South Asia. This unequal financial access results in varying capacities for innovation and entrepreneurship across regions, contributing to differing levels of carbon emissions. By analyzing both developed and developing countries, this study identifies key trends and regional disparities that influence global sustainability. The findings align with international frameworks like the Paris Agreement and the discussions held at COP conferences, emphasizing the role of inclusive financial systems in addressing climate change.

One of the most pressing global challenges is the limited access to financial resources for entrepreneurs aiming to develop environmentally friendly innovations. Without adequate funding, these innovations often fail to reach scale, undermining global efforts to reduce carbon emissions. The Global Innovation Index (GII) of 2022 highlights the persistent divide between developed and developing countries in innovation capabilities, largely due to unequal financial access. Entrepreneurs in developing regions face significant barriers in accessing capital for green technologies, leading to higher emissions (Teixeira et al., 2018). This study links these practical gaps to real-world challenges by emphasizing how targeted financial policies can address sustainability issues. By promoting financial access for green entrepreneurship, policymakers can directly contribute to global sustainability goals and climate action efforts.

This study is guided by the following research questions:

1. How does financial access influence innovation and entrepreneurship?
2. What is the impact of innovation and entrepreneurship on carbon emissions?
3. How does financial access moderate the relationship between innovation and carbon emissions, as well as entrepreneurship and carbon emissions?

The objectives of the study are to:

- Investigate the effect of financial access on innovation and entrepreneurship.
- Examine the relationship between innovation and carbon emissions.
- Analyze the relationship between entrepreneurship and carbon emissions.
- Assess the moderating role of financial access in reducing the environmental impact of entrepreneurship and innovation.

These questions and objectives frame the study's focus on understanding the mechanisms through which financial access promotes sustainable development.

This study makes significant theoretical and practical contributions to the literature on financial access, innovation, entrepreneurship, and carbon emissions:

Theoretical Contributions:

1. Filling Gaps in Literature: While existing studies focus on financial development and carbon emissions (Ababio et al., 2023; Li & Wei, 2021; Jiang & Ma, 2019), this research emphasizes the critical role of financial access in driving innovation and entrepreneurship. By examining the bidirectional relationship between financial access and innovation, this study provides a dynamic perspective on the interplay between these variables.
2. Expanding the Scope**:** Unlike region-specific studies, this research adopts a global perspective, analyzing data from 149 countries to reveal regional disparities and their impact on global carbon emissions. This comprehensive approach offers a nuanced understanding of how financial systems contribute to sustainability in different contexts.
3. Examining Moderation Effects: The study highlights how financial access moderates the relationship between innovation, entrepreneurship, and carbon emissions. This insight underscores the dual-edged nature of financial systems, which can either exacerbate or mitigate environmental impacts depending on how resources are allocated.

Practical Contributions:

1. Policy Implications: The findings underscore the need for financial policies that directly promote green technologies and sustainable entrepreneurship. Policymakers can use these insights to design inclusive financial systems that incentivize environmentally friendly investments.

2. Addressing Global Challenges: By linking financial access to real-world issues like climate change, the study provides actionable recommendations for reducing carbon emissions through targeted financial interventions.
3. Guidance for Financial Institutions: The study offers valuable guidance for financial institutions, emphasizing the importance of supporting entrepreneurs in developing green technologies. Tailored financial products such as green loans and grants can help bridge the gap between financial access and sustainable development.

This study addresses critical theoretical and practical gaps by examining the relationship between financial access, innovation, entrepreneurship, and carbon emissions on a global scale. By exploring the bidirectional relationship between financial access and innovation, it provides a nuanced understanding of how inclusive financial systems can drive sustainable development. The study's findings contribute to global discussions on sustainability, offering policymakers and financial institutions actionable insights for reducing carbon emissions and promoting green entrepreneurship.

2. Literature review

2.1. Theoretical framework

The theoretical foundation of this study lies in three key frameworks: the Environmental Kuznets Curve (EKC), the Resource-Based View (RBV), and Institutional Theory (IT). These theories offer insights into how financial resources and institutional structures influence innovation, entrepreneurship, and carbon emissions globally.

The EKC describes an inverted-U relationship between environmental degradation and economic development. In the early stages of economic growth, rapid industrialization and energy consumption lead to increased environmental harm. However, as economies reach higher levels of development, carbon emissions decline due to the adoption of cleaner technologies and sustainable policies (Rashid Gill et al., 2018). By integrating financial access into this framework, the study highlights how innovation and entrepreneurship mitigate the environmental impacts of growth.

For example, OECD countries initially experienced significant carbon emissions during industrialization but later transitioned to cleaner energy and sustainable practices through eco-friendly innovations (Churchill et al., 2018). Financial access plays a critical role in this transition by enabling the development and deployment of green technologies (Ababio & Yiadom, 2023; Chen et al., 2019). EKC provides policymakers with a roadmap for tailoring interventions to different stages of development, such as promoting financial inclusion in earlier stages and supporting advanced technologies in later stages (Ofosu-Mensah et al., 2023; Yiadom & Abdul-Mumuni, 2022; Sarkodie & Ozturk, 2020).

The RBV, introduced by Wernerfelt (1984), emphasizes the strategic use of unique organizational resources to achieve competitive advantages. In this study, RBV identifies financial resources, innovation, and entrepreneurial capabilities as critical for reducing carbon emissions. Firms with robust financial access can invest in eco-friendly technologies, sustainable practices, and energy-efficient production methods, aligning profitability with environmental responsibility (Yiadom et al., 2024; Collins, 2021).

Innovation under RBV is pivotal in addressing environmental challenges. Firms fostering innovation can develop eco-friendly products, green business models, and advanced production techniques that reduce pollution. These strategic investments reinforce RBV's assertion that rare, valuable, and inimitable resources enhance competitiveness. Financial access, as a key resource, links innovation and entrepreneurship with sustainable practices, demonstrating how resource utilization can drive environmental stewardship.

Institutional Theory explores how formal structures (laws, regulations) and informal structures (culture, norms) influence organizational behavior. Formal mechanisms like carbon taxes, incentives for eco-friendly production, and sustainability regulations compel firms to adopt sustainable practices (Gupta et al., 2020). Informal structures, including societal norms and expectations, further drive sustainability integration into business operations (Lewis et al., 2019; Mensah et al., 2018).

IT provides critical insights into why organizations conform to or deviate from sustainability norms. For instance, firms in regions with weak institutional frameworks may neglect environmental regulations, exacerbating emissions. Conversely, strong institutional enforcement promotes compliance and supports sustainable entrepreneurship. By examining how institutional structures influence financial access and entrepreneurial strategies, IT highlights the broader dynamics shaping global sustainability (Berrone et al., 2020).

2.1.1. Application of theories

These frameworks are systematically applied in this study to analyze the relationships between financial access, innovation, entrepreneurship, and carbon emissions. The EKC provides a macro-level perspective on how financial access moderates the relationship between economic growth and carbon emissions. Financial resources enable early-stage economies to adopt sustainable technologies, helping them transition past the EKC turning point. RBV offers a micro-level view, emphasizing how firms strategically utilize resources to drive innovation and eco-friendly entrepreneurship. IT bridges these perspectives by demonstrating how formal policies and informal norms influence sustainable practices across regions.

For example, financial access enables firms to overcome initial barriers to adopting green technologies and practices. Combining insights from EKC, RBV, and IT, this study develops a robust framework for examining the global impact of financial access on reducing carbon emissions through sustainable entrepreneurship and innovation.

While the EKC is widely studied, conflicting findings exist regarding its applicability to developing versus developed nations. Developed economies have successfully transitioned to cleaner energy, but many developing countries remain on the EKC's rising curve due to limited financial access and weak institutional frameworks (Amankwah et al., 2024; Sarkodie & Ozturk, 2020). This study

incorporates financial access as a moderating factor to address these disparities and accelerate sustainable transitions.

Similarly, RBV's application to environmental sustainability is underexplored. This study extends RBV by showing how financial access and innovation serve as competitive advantages in reducing carbon emissions. IT further enriches this analysis by considering how societal norms influence entrepreneurial decisions toward green investments, bridging the gap between formal and informal institutional dynamics.

The frameworks offer actionable insights for businesses and policymakers. RBV highlights the role of financial access and innovation as sustainable competitive advantages. For instance, firms investing in renewable energy technologies can lower operational costs while reducing emissions, achieving profitability and sustainability. EKC provides policymakers with strategies to address environmental impacts at different stages of development, such as promoting financial inclusion in early industrialization and incentivizing advanced green technologies in later stages.

IT underscores the role of institutional frameworks in fostering sustainable behavior. Carbon pricing, government incentives, and societal support for green initiatives are critical in shaping entrepreneurial actions. By integrating financial access into sustainability strategies, entrepreneurs can scale environmentally friendly technologies, contributing to global efforts to combat climate change.

These theoretical frameworks directly inform the study's methodology. The selection of financial access, innovation, and entrepreneurship as key variables is grounded in RBV's focus on strategic resource utilization and IT's emphasis on institutional dynamics. Similarly, the use of two-stage least squares (2SLS) estimation aligns with the EKC framework, ensuring robust analysis of the bidirectional relationships between financial access, innovation, and carbon emissions. This integration ensures the research design is well-grounded in theoretical insights while addressing critical sustainability challenges.

2.2. Empirical review

The empirical literature on financial access, innovation, entrepreneurship, and carbon emissions reveals a multifaceted landscape where these interconnected variables hold the potential to significantly reduce carbon emissions. Several studies have found positive relationships among these variables, indicating their critical role in promoting environmentally sustainable practices.

Access to sufficient financial resources has been identified as a key facilitator of environmental initiatives. Acheampong et al. (2020) demonstrate a significant positive relationship between financial access and the adoption of eco-friendly practices by firms. This implies that when firms have greater access to financial resources, they can invest in green technologies, leading to notable reductions in carbon emissions. The study underscores the importance of varied financing options, which allow firms to implement sustainable technologies and practices, thereby fostering a positive correlation between financial access and environmental sustainability.

Innovation, working in tandem with financial access, is pivotal in shaping environmentally friendly practices. From the early work of Schumpeter to contemporary studies by Azam et al. (2022) and Y. Chen et al. (2021), innovation has been recognized as essential for fostering economic development and mitigating carbon emissions. These studies highlight that eco-friendly technologies and innovative models significantly contribute to reducing carbon emissions. Entrepreneurs leveraging innovation and creative problem-solving skills can produce sustainable products and services, establishing a positive relationship between innovation and environmental sustainability. With adequate financial resources coupled with innovation, countries can significantly mitigate carbon emissions, ensuring a cleaner environment for business operations.

Entrepreneurship, bolstered by access to financial resources, also plays a crucial role in promoting eco-friendly practices. Ding et al. (2022) and Udemba et al. (2022) found that entrepreneurial capacity, especially when it promotes eco-friendly activities, is strengthened by ample financing options. Their studies indicate that the intersection of financial access and entrepreneurial advances is pivotal in mitigating carbon emissions. This demonstrates a positive relationship among financial access, innovation, entrepreneurship, and the reduction of carbon emissions, emphasizing the importance of supporting entrepreneurs with sufficient financial resources to foster sustainable practices.

While the majority of studies highlight positive and significant relationships between financial access, innovation, entrepreneurship, and carbon reduction, some studies reveal nuanced perspectives and potential negative relationships. Understanding these counterintuitive instances is crucial for a holistic understanding of the complex dynamics at play. Shahbaz et al. (2022) and Habiba and Xinbang (2022) point out that the profit-seeking needs of financially stable companies can lead to increased carbon emissions. They argue that the relationship between financial access and carbon reduction is not always linear, as firms may invest in profit-maximizing ventures that inadvertently increase carbon emissions. This suggests that the relationship between financial access and carbon emissions varies, necessitating targeted policies to ensure financial resources are used to genuinely reduce emissions.

Empirical evidence also shows that environmentally friendly innovations can sometimes lead to negative outcomes. Erdoğan et al. (2020) concede that while innovative technologies may reduce per unit energy consumption, they often result in increased overall energy consumption and, consequently, higher carbon emissions. This indicates that firms, by becoming more innovative, may increase their carbon footprint, leading to a more degraded environment. Organizations relying on innovation to counter carbon emissions must avoid using innovation as a cover for increased production and pollution. Entrepreneurs devising innovations for resource extraction, for example, may inadvertently increase pollution, highlighting that entrepreneurship is not immune to negative environmental impacts.

Additionally, some studies find ambivalent relationships between financial access, innovation, entrepreneurship, and carbon emissions. Emenekwe et al. (2022) argue that the effects of financial access on carbon emissions are context-dependent, capable of supporting both environmentally friendly and carbon-intensive activities. This dual nature of financial access underscores the need for comprehensive strategies to ensure that funds are used for projects that genuinely mitigate carbon emissions. Similarly, the

relationship between innovation and carbon emissions is not conclusive. In certain instances, innovation reduces carbon emissions, while in others, it exacerbates them, suggesting that the impact of innovation on environmental sustainability varies by context.

2.3. Conceptual framework

Conceptual framework is a pictorial view of the relationship between variables of a study. In this study, the varied relationships among the relevant variables are demonstrated by their conceptual interconnections. In Fig. 1 below, the relationships among the variables are shown.

As demonstrated above, the variables to the left are the independent variables and a change in the dependent variable (the one to the right) is caused by those to the left. While it is shown that financial access, innovation, and entrepreneurship collectively influence the level of carbon emissions it is expected that some of the dependent variables may be interconnected also. For instance, Fombang and Adjasi (2018) revealed that entrepreneurs become more innovative when they have access to sufficient financial resources. This is because both entrepreneurship and innovation as much as they influence the level of carbon emissions, have a long history of influencing innovations.

3. Methodology

This study utilizes a robust econometric framework to investigate the relationships between financial access, innovation, entrepreneurship, and carbon emissions. The methodology ensures that the findings are statistically sound and addresses endogeneity concerns inherent in the dataset. The analysis uses a global panel dataset from 149 countries spanning 24 years (2000–2023). Data were collected from the World Development Indicators hosted by the World Bank (2023). Detailed descriptions and summary statistics of the variables are provided in Tables 1 and 2.

3.1. Model specification

The study followed Yiadom et al. (2023b) employs two-stage least squares (2SLS) estimation to address potential endogeneity issues. The following empirical models are specified.

In the first stage, instrumental variables are created and regressed against the endogenous variables. The instrumental variables are correlated with the endogenous variables but are not directly involved in the regression. The inclusion of the instrumental variables is to capture the variations in the endogenous variables that are not related to the error term.

$$X_{1i} = \pi_0 + \pi_1 Z_{1i} + \pi_2 Z_{2i} + \ldots\ldots\ldots\ldots\ldots\ldots + \pi_k Z_{Ki} + \mu_i \tag{1}$$

Where X_{1i} is the endogenous variable, $\pi_{1i,}\pi_{2i}\ldots\ldots\ldots\ldots\ldots\ldots, \pi_k Z_{ki}$ are the instrumental variables. μ_i is the error term of the regression and captures the unobserved factors affecting X_{1i} that are not accounted for by the instrumental variables. $\pi_0, \pi_{1,}\pi_2\ldots\ldots\ldots\ldots\pi_k$ can be estimated using the ordinary least square (OLS). To ensure that the instruments are not directly affecting the dependent variable but are only influencing the endogenous variable through their correlation with it, the assumption of exogeneity is followed at this stage of the process.

In the second stage, the estimated value of the endogenous variable, $\overline{X}_{1i}$ from the first stage is substituted into the main equation at the second stage. The main equation includes both the exogeneous and endogenous variables. In the second stage of the process, the estimation is done using the Ordinary Least Squares (OLS).

$$Y_i = \beta_0 + \beta_1 \widehat{X}_{1i} + \beta_2 X_{2i} + \ldots\ldots\ldots\ldots + \beta_p X_{pi} + \epsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \tag{2}$$

Where Y_i is the dependent variable, $\widehat{X}_{1i}$ is the predicted value of the endogenous variable estimated in the previous equation, $X_{21,}X_{3i,}\ldots$ $.,X_{pi}$ are the exogenous variables and ϵ_i is the error term.

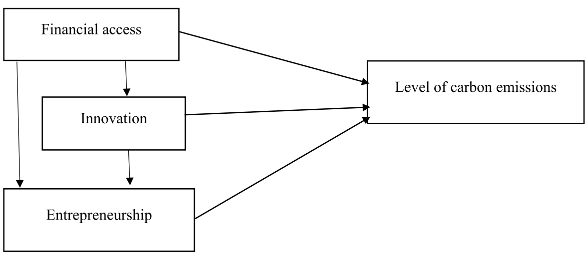


Fig. 1. Conceptual framework.
Source: Authors' computations (2024)

Table 1
Variable descriptions.

Variable	Description	Definition
cemission	Carbon emission (CO2)	CO2 emissions metric tons per capita
lnpatent	Natural log of Patent	Total number of Patent applications
techexport	Technology export	High-technology exports are products with high R&D intensity
rdexp	Research and development expenditure	R&D expenditure as a percentage of GDP
lnresearchers	Natural log of researchers	Researchers in R&D (per million people)
lnnewbus	Natural log of new businesses	Total number of New businesses registered
newbusdensity	New business density	New business density is new registrations per 1000 people
easebus	Ease of doing business	Ease of doing business score (0 = lowest performance to 100 = best performance)
selfemployed	Self employed	Total number of Self-employed, as a percentage of total employment
dcredit	Domestic credit	Domestic credit provided by financial sector (% of GDP)
lnborrow	Natural log of borrowers	Borrowers from commercial banks (per 1000 adults)
atm	Natural log of Automated teller machines	Automated teller machines (ATMs) (per 100,000 adults)
lngdppc	Natural log of GDP per capital	Gross Domestic Product divided by the total population
lnpop	Natural log of total population	Total population
fdipercent	Foreign direct investment	FDI as a percentage of GDP
trade	Trade	Total value of trade as a percentage of GDP
developdummy	Level of development	Dummy variable with a value of 1 if a country is classified by World Bank as developed and 0 otherwise

Source: Authors' computations (2024).

Table 2
Descriptive statistics.

Variable	Obs	Mean	Std. Dev.	Min	Max
Carbon emission	3576	0.234	0.131	0.033	0.86
Innovation:					
lnpatent	3576	8.101	2.041	1.099	14.277
techexport	3576	11.7	8.574	0	95.618
rdexp	3576	1.004	0.692	0.013	5.706
lnresearchers	3576	7.346	1.021	1.769	9.003
Entrepreneurship:					
lnnewbus	3576	9.877	1.359	2.303	13.56
newbusdensity	3576	4.111	4.332	0.017	82.867
easebus	3576	60.667	6.021	20.925	87.166
selfemployed	3576	40.887	25.913	0.393	95.098
Financial access:					
dcredit	3576	54.046	41.461	0.002	304.575
lnborrow	3576	5.058	0.999	−3.912	7.061
lnatm	3576	44.436	33.715	0.02	228.42
Control variables:					
lngdppc	3576	8.693	1.478	5.542	11.766
lnpop	3576	16.1	1.803	11.032	21.072
fdipercent	3576	5.029	14.351	−394.472	249.108
trade	3576	85.646	53.896	2.699	437.327

Source: Authors' computations (2024).

3.2. Empirical model specification

The following empirical models are specified to achieve the objectives of the study.
First, we test the effect of financial access on innovations in equation (3.3).

$$innovation_{it} = \beta_1 finaccess_{it} + \sum_n \beta_n X_{n,it} + \beta_2 \theta_{j,it} + \mu_t + \varepsilon_{it} \ldots\ldots\ldots\ldots \quad (3.3)$$

Where $innovation_{it}$ is the innovation of a country i at time t. This depends on access to financial products where β_1 is the coefficient of financial access. X is a host of exogenous variables included in the model as control variables. θ captures the level of development in the various countries. It is a dummy variable with a value of 1 if a country is classified by World Bank as developed and 0 otherwise. Again, β_n and β_2 are the coefficients to be estimated. μ_t is the time invariant terms and ε_{it} captures any remaining errors in the series. Table 1 contains the details of all variables.

Second, the study examines the enhanced effect of innovation (motivated by financial access) on carbon emission in equation (3.4).

$$cemission_{it} = \beta_3 \widehat{innovation}_{it} + \sum_n \beta_n X_{n,it} + \beta_4 \theta_{j,it} + \omega_t + \eta_{it} \ldots\ldots\ldots\ldots\ldots \quad (3.4)$$

This objective examines how *innovation*, influenced by financial access as in equation (3.3). above, determines the amount of carbon emission recorded by a country i at time t. $\beta_1, \beta_2, \beta_3, \beta_4, \beta_n$ represents the parameters to be estimated.

In addition, the effect of innovation and financial access on entrepreneurship is examined in equation (3.5).

$$entrep_{it} = \beta_1 innovation_{it} + \beta_1 Faccess_{it} + \sum_n \beta_n X_{n,it} + \beta_2 \theta_{j,it} + \mu_t + \varepsilon_{it} \ldots\ldots \quad (3.5)$$

This objective investigates how *innovation* and financial access (*faccess*) affect entrepreneurship. As a result, both innovation and financial access are acting as independent variables on the dependent variable, entrepreneurship. Indicating that entrepreneurs require financial access and innovation to tackle carbon emission.

In equation (3.6), the study examines the effect of sustainable entrepreneurship on carbon emission.

$$cemission_{it} = \beta_5 \widehat{entrep}_{it} + \sum_n \beta_n X_{n,it} + \beta_6 \theta_{j,it} + \omega_t + \eta_{it} \ldots\ldots\ldots\ldots\ldots \quad (3.6)$$

This objective requires the estimated value of entrepreneurship in the previous objective as the independent variable together with others to be regressed on carbon emission.

Finally, equations (3.7) and (3.8) examine the moderating role of financial access on the relationship between innovation, entrepreneurship and carbon emissions.

$$cemission_{it} = \beta_7 \widehat{innovation}_{it} + \beta_8 (faccess \times innovate)_{it} \sum_n \beta_n X_{n,it} + \beta_9 \theta_{j,it} + \omega_t + \eta_{it} \ldots\ldots \quad (3.7)$$

$$cemission_{it} = \beta_{10} \widehat{entrep}_{it} + \beta_{11} (faccess \times entrep)_{it} \sum_n \beta_n X_{n,it} + \beta_{12} \theta_{j,it} + \omega_t + \eta_{it} \ldots\ldots \quad (3.8)$$

The key variables include carbon emissions, innovation (lnpatent, techexport, rdexp, lnresearchers), entrepreneurship (lnnewbus, newbusdensity, easebus, selfemployed), and financial access (dcredit, lnborrow, lnatm). Innovation metrics cover patenting activity, technology exports, research expenditure, and researcher density. Entrepreneurship is measured through new business creation, business density, ease of doing business, and self-employment rates. Financial access encompasses variables like domestic credit, borrowing, and ATM accessibility. Control variables include GDP per capita, population size, foreign direct investment percentage, and trade volume. These variables collectively inform the study's analysis of their interrelationships.

Principal component analysis is used to generate an index for innovation, entrepreneurship, and financial access.

3.3. Diagnostic tests for OLS assumptions

Before employing 2SLS, diagnostic tests (see Appendix A, B, C, D, E, F, G) were conducted to ensure the appropriateness of ordinary least squares (OLS):

i. Linearity: Scatterplots confirmed linear relationships between dependent and independent variables.
ii. Homoscedasticity: The Breusch-Pagan test indicated no significant heteroscedasticity.
iii. No Autocorrelation: The Wooldridge test for panel data showed no first-order autocorrelation.
iv. No Multicollinearity: Variance inflation factors (VIF) for all independent variables were below 10, confirming no severe multicollinearity.
v. Normality of Residuals: The Shapiro-Wilk test validated that residual were normally distributed.

3.4. Addressing endogeneity

Endogeneity concerns were addressed using the following approaches:

i. Wald Test for Endogeneity: The test confirmed significant correlations between independent variables and the error term.
ii. Hausman Test: A statistically significant result indicated that endogeneity is present, necessitating 2SLS.

3.5. Instrumental variables (IVs) and their validation

The study uses financial access measures (e.g., domestic credit) as instrumental variables. These IVs satisfy the two key conditions for validity:

i. Relevance: Strong correlation with endogenous variables, confirmed via first-stage F-statistics.
ii. Exogeneity: No correlation with the error term, as validated by the Sargan-Hansen test.

3.6. Implementation of 2SLS

In the first stage, endogenous variables (e.g., innovation) were regressed on the IVs. The predicted values from these regressions were used in the second stage as inputs for the main equations. This approach ensures unbiased and consistent parameter estimates.

3.7. Correcting missteps in model application

The initial use of fitted values for innovation and entrepreneurship in moderation models (Equations (3.7) and (3.8)) was revised. Fitted values were replaced with raw observed variables to align with the assumptions of 2SLS and avoid invalid inferences.

3.8. Robustness checks

Robustness checks included decomposing innovation and entrepreneurship into sub-components and re-estimating their impacts on carbon emissions. Consistent results across decomposed models reinforced the reliability of findings.

4. Results and discussions

4.1. Summary results

From Table 2, the means and standard deviations provide insights into the central tendency and variability of the variables. For carbon emissions, the mean is 0.234 with a standard deviation of 0.131, indicating moderate variability. Innovation variables, such as lnpatent and rdexp, have means around 8 to 9, with standard deviations ranging from 1 to 2, reflecting some variability in innovation metrics. Entrepreneurship indicators, like lnnewbus and easebus, show means around 9 to 60, with standard deviations ranging from 1 to 25, suggesting considerable variability.

The variance inflation factor (VIF) and correlation matrix in Tables 3 and 4 provide insights into how independent variables interact. Correlation coefficients range from −1 to +1, indicating negative or positive correlations. Strong correlations suggest potential multicollinearity issues, impacting dependent variables. A VIF of 1 implies no correlation, while values above 10 signal severe multicollinearity, affecting regression coefficients. Fortunately, results suggest manageable multicollinearity levels, ensuring the

Table 3
Variable inflation factor.

	VIF	1/VIF
lnpatent	1.940	0.515
techexport	1.810	0.554
rdexp	1.660	0.601
lnresearchers	1.620	0.617
lnnewbus	1.400	0.712
newbusdensity	1.390	0.722
easebus	1.370	0.729
selfemployed	1.250	0.799
dcredit	1.220	0.820
lnborrow	1.210	0.828
atm	1.180	0.845
lngdppc	1.180	0.846
lnpop	1.140	0.875
fdipercent	1.120	0.894
trade	1.080	0.922
developdummy	1.11	0.938
	1.370	

Source: Authors' computations (2024).

study's validity. These preliminary findings assure the study's progression without significant interference from multicollinearity, enhancing confidence in subsequent analyses.

4.2. The dynamics of innovation, entrepreneurship, and carbon emissions

The study's objectives are to investigate the effect of innovation on carbon emissions, the effect of entrepreneurship on carbon emissions, the impact of financial access on innovation and entrepreneurship, and the moderating role of financial access on the relationships between innovation and carbon emissions, and between entrepreneurship and carbon emissions.

First, the study employs the Ordinary Least Square (OLS) to examine the linear effect of entrepreneurship, innovation, and financial access on carbon emission. The results in Table 5 unveil the intricate relationship between carbon emissions and various independent variables. Entrepreneurship exhibits a significant positive correlation with carbon emissions, echoing Lin et al.'s (2024) findings on Chinese cities. Caution is warranted in fostering entrepreneurship to prevent exacerbating carbon emissions. Conversely, innovation displays a negative albeit marginal association with carbon emissions, aligning with Dauda et al.'s (2019) insights on the efficacy of innovative strategies in emission reduction. Financial access, GDP per capita, and population also exhibit positive correlations with carbon emissions, albeit with varying significance levels. Financial access's positive impact is pronounced, with a 1% increase contributing to a 0.0635% rise in emissions, underscoring its pivotal role in shaping environmental outcomes. Similarly, GDP per capita and population growth exert notable albeit differing degrees of influence on carbon emissions. These findings highlight the multifaceted dynamics underpinning carbon emissions and underscore the importance of informed policy interventions to mitigate environmental degradation.

Models 2,3,4, and 5 in Table 6 contains the baseline results of the study.

4.2.1. Financial access and innovation

In Model 2 of Table 6, where innovation is the dependent variable, the analysis reveals a positive and significant effect of financial access on innovation, with a p-value of 1%. Specifically, a unit increase in financial access leads to a 0.0971-unit increase in innovation, holding other factors constant. This finding aligns with García-Quevedo et al. (2018), who noted that while financial access facilitates innovation, financial constraints can inhibit it. The positive relationship observed here underscores the critical role of financial resources in driving innovation. Without adequate financial access, entities may struggle to pursue innovative endeavors, highlighting the necessity of financial infrastructure to support creative activities and technological advancements.

Interestingly, the model also shows that a unit increase in GDP per capita correlates with a 33.3% decrease in innovation, significant at the 1% level. This inverse relationship suggests that as countries develop and GDP per capita increases, the drive for innovation diminishes, potentially because economic stability reduces the urgency for innovative solutions. However, during economic downturns, innovation may become a critical strategy for revitalization, supporting the contention that innovation thrives in response to economic challenges. Additionally, population and trade both exhibit negative but significant relationships with innovation, albeit their impacts are relatively minimal compared to other factors.

4.2.2. Innovation and carbon emissions

Model 3 in Table 5 explores the impact of innovation, driven by financial access, on carbon emissions. The results indicate a significant negative relationship between innovation and carbon emissions, with a unit increase in innovation leading to a 0.0226-unit decrease in carbon emissions at the 1% significance level. This suggests that innovation can lead to the development of environmentally friendly technologies and practices that reduce carbon emissions. This is consistent with findings by Ostadzad (2022) and Töbelmann and Wendler (2020), who demonstrated that innovative European economies have successfully reduced their carbon footprints. Consequently, countries aiming to lower carbon emissions should prioritize fostering innovation as a strategic approach.

The model also confirms the crucial role of financial access in enhancing innovation. A unit increase in financial access results in a 0.0274-unit increase in innovation, underscoring the necessity of financial resources for fostering innovative activities. This aligns with previous studies by Le et al. (2020), Yao and Tang (2021), and Zhao & Yang (2020), which showed that financial access boosts energy consumption for production, often leading to increased carbon emissions. This dual relationship suggests that while financial access promotes innovation, it can also contribute to higher emissions if not channeled towards sustainable practices.

Additionally, GDP per capita has a positive and significant relationship with carbon emissions. A unit increase in GDP per capita results in a 0.385% increase in carbon emissions at the 1% significance level. This reflects the reality that economic growth often entails increased industrial activities and energy consumption, leading to higher emissions, as noted by Yang et al. (2021). Population growth also significantly influences carbon emissions, with a unit increase in population resulting in a 0.956% increase in emissions. This finding aligns with T. Yang & Wang (2020), who highlighted that higher populations lead to greater energy consumption for both domestic and commercial purposes, thus increasing carbon emissions.

4.2.3. Innovation, financial access, and entrepreneurship

Model 4 in Table 6 examines the relationship between innovation, financial access, and entrepreneurship. The results show that a unit increase in innovation leads to a 0.134-unit increase in entrepreneurship, significant at the 1% level. This underscores the essential role of innovation in entrepreneurial activities, as innovative entrepreneurs can better market their ideas and solutions. Singh and Gaur (2018) and Yunis et al. (2018) highlighted the importance of innovation for entrepreneurship, particularly in addressing significant challenges like poverty and hunger.

Furthermore, financial access significantly boosts entrepreneurship. A unit increase in financial access leads to a 0.583-unit

Table 4
Matrix of correlations.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) cemission	1.000															
(2) lnpatent	0.168	1.000														
(3) techexport	0.043	0.117	1.000													
(4) rdexp	−0.097	0.219	0.231	1.000												
(5) lnresearchers	0.009	0.107	0.139	0.510	1.000											
(6) lnnewbus	0.131	0.137	0.174	0.097	0.067	1.000										
(7) newbusdensity	0.040	−0.072	0.182	0.056	0.120	0.159	1.000									
(8) easebus	0.007	−0.062	0.158	0.169	0.127	0.127	0.176	1.000								
(9) selfemployed	−0.359	0.042	−0.183	−0.260	−0.200	−0.075	−0.188	−0.314	1.000							
(10) dcredit	0.157	0.073	0.320	0.397	0.253	0.188	0.300	0.295	−0.564	1.000						
(11) lnborrow	0.220	−0.027	0.141	0.077	0.097	0.138	0.123	0.236	−0.419	0.323	1.000					
(12) atm	0.104	0.061	0.189	0.327	0.226	0.199	0.151	0.326	−0.484	0.492	0.384	1.000				
(13) lngdppc	0.067	−0.030	−0.000	−0.006	0.043	−0.045	0.107	0.054	−0.062	0.122	0.195	0.090	1.000			
(14) lnpop	0.124	0.079	0.099	−0.059	−0.065	0.118	−0.069	0.033	0.018	−0.004	0.058	−0.043	−0.185	1.000		
(15) fdipercent	−0.010	0.019	0.013	−0.012	0.042	−0.086	0.104	0.020	−0.057	0.033	0.002	−0.005	0.074	−0.131	1.000	
(16) trade	−0.011	−0.002	0.018	0.004	0.089	−0.006	0.112	0.045	−0.157	0.103	0.067	0.072	0.353	−0.384	0.238	1.000

Source: Authors' computations (2024).

Table 5
OLS Results – Determinants of carbon emission.

VARIABLES	(1)
	cemission
entrep	0.0239*
	(0.00214)
innovation	−0.00706*
	(0.00173)
faccess	0.00635*
	(0.00218)
lngdppc	0.0540*
	(0.0154)
lnpop	0.00875*
	(0.00126)
fdipercent	−0.0662
	(0.0150)
trade	−0.0491
	(0.0455)
developdummy	0.02505
	(0.01254)
Constant	0.0511
	(0.0259)
Observations	3576
R-squared	0.951
Log Lik	901.3

Standard errors in parentheses.
*p < 0.01, p < 0.05, *p < 0.1.
Source: Authors' computations (2024).

Table 6
Two-staged least squares – baseline results.

VARIABLES	(2)	(3)	(4)	(5)
	innovation	cemission	entrep	cemission
entrep				−0.162*
				(0.0224)
innovation		−0.0226*	0.134*	−0.00609
		(0.00218)	(0.0315)	(0.00306)
faccess	2.283*	0.0274*	0.583*	0.124*
	(0.0971)	(0.00182)	(0.0173)	(0.0145)
lngdppc	−0.333*	0.00385	−0.0165	0.000842
	(0.0365)	(0.00158)	(0.0123)	(0.00277)
lnpop	−0.0909*	0.00956*	0.0409*	0.0162*
	(0.0284)	(0.00130)	(0.00999)	(0.00240)
fdipercent	0.00288	3.49e-05	0.00317*	0.000557
	(0.00335)	(0.000154)	(0.00119)	(0.000276)
trade	−0.00293*	0.00102	0.00206*	0.000347*
	(0.00102)	(0.00465)	(0.000358)	(9.30e-05)
developdummy	0.0113*	0.0137*	0.0670*	0.0810*
	(0.00109)	(0.0091)	(0.0158)	(0.0112)
Constant	4.598*	0.0458*	−0.707*	−0.0658
	(0.607)	(0.0266)	(0.206)	(0.0478)
Observations	3576	3576	3576	3576
R-squared	0.928	0.783	0.725	0.817
Log Lik	−754.7	−674.3	−549.2	−367.4

Standard errors in parentheses.
*p < 0.01, p < 0.05, *p < 0.1.
Source: Authors' computations (2024).

increase in entrepreneurship, indicating that financial resources are vital for entrepreneurial success. Dutta and Meierrieks (2021) argued that financial availability enables entrepreneurs to undertake more ambitious and potentially rewarding projects. This finding highlights the necessity of financial support at every stage of the entrepreneurial journey.

4.2.4. Sustainable entrepreneurship and carbon emissions

Model 5 in Table 6 investigates the effects of sustainable entrepreneurship on carbon emissions. The results indicate that sustainable entrepreneurship, which incorporates environmentally friendly practices, significantly reduces carbon emissions. A unit

increase in sustainable entrepreneurship leads to a 0.162-unit decrease in carbon emissions at the 1% significance level. This finding is in contrast to traditional entrepreneurship, which may not prioritize environmental concerns. Hoogendoorn et al. (2019) found that sustainable entrepreneurship diverges from traditional business models by integrating environmental considerations, thus reducing carbon emissions.

The impact of innovation on carbon emissions remains negative and significant but with minimal impact. A unit increase in innovation leads to a 0.00609-unit decrease in carbon emissions at the 1% significance level. This consistency across models underscores the role of innovation in mitigating environmental impacts, although its effect size is relatively small.

Financial access, however, shows a complex relationship with carbon emissions. A unit increase in financial access leads to a 0.124-unit increase in carbon emissions, highlighting the potential for higher emissions with greater financial access. This is higher compared to the previous model, indicating that financial access can lead to increased energy consumption and emissions if not directed towards sustainable practices. Khan & Ozturk (2021) emphasized that financial access often drives business expansion and energy consumption, leading to higher emissions.

Population growth also significantly impacts carbon emissions. A unit increase in population leads to a 1.62% increase in carbon emissions at the 1% significance level, a substantial increase from previous findings. Ribeiro et al. (2019) noted that larger populations typically consume more energy, leading to higher emissions. This suggests that populous countries face greater challenges in managing carbon emissions.

Finally, trade exhibits a positive but relatively negligible impact on carbon emissions. While trade can contribute to economic growth and energy consumption, its effect on emissions is less significant compared to other factors like population and financial access.

This study highlights the intricate relationships between financial access, innovation, entrepreneurship, and carbon emissions. Financial access significantly boosts innovation and entrepreneurship, which can contribute to economic growth and, in some cases, higher carbon emissions. However, fostering sustainable entrepreneurship and directing financial resources towards environmentally friendly innovations can effectively reduce carbon emissions. Policymakers should thus focus on creating financial systems that support sustainable practices and innovation, balancing economic growth with environmental sustainability.

4.3. Moderating effect of financial access on carbon emissions, innovation, and entrepreneurship nexus

The findings in Table 7 reveal that financial access significantly moderates the relationship between innovation and carbon emissions. In Model 6, the interaction term between financial access and innovation (faccess*innovate) is −0.349 and statistically significant at the 5% level. This suggests that increased financial access can mitigate the positive impact of innovation on carbon emissions. In essence, greater financial resources enable the adoption of cleaner technologies and more sustainable practices, thus reducing the environmental impact of innovative activities (see Table 8).

Table 7
Moderation effect of financial access on carbon emissions, innovation, and entrepreneurship nexus.

VARIABLES	(6)	(7)
	cemission	cemission
faccess*innovate	−0.349	
	(0.169)	
innovation	0.124*	
	(0.0641)	
faccess	0.170	0.00495
	(0.0726)	(0.00206)
lngdppc	−0.0476*	0.00226
	(0.0268)	(0.00173)
lnpop	0.0191	0.00736*
	(0.00824)	(0.00129)
fdipercent	−0.000181	−0.0998
	(0.00821)	(0.00147)
trade	0.0199	−0.0185
	(0.00264)	(0.00453)
Faccess*entrep		−0.0169*
		(0.00406)
entrep		0.0199*
		(0.00230)
Constant	0.555*	0.118*
	(0.289)	(0.0305)
Observations	3576	3576
R-squared	0.728	0.730

Standard errors in parentheses.
*p < 0.01, p < 0.05, *p < 0.1.
Source: Authors' computations (2024).

Table 8
Decomposition: Effect of innovations on various entrepreneurship.

VARIABLES	(8)	(9)	(10)	(11)
	lnnewbus	newbusdensity	selfemployed	easebus
techexport	0.0156*	0.0602*	0.0439	0.0409*
	(0.00271)	(0.00846)	(0.0409)	(0.0116)
lnpatent	0.0735*	0.186*	1.154*	0.311*
	(0.0109)	(0.0342)	(0.165)	(0.0470)
rdexp	−0.0559	0.692*	1.435	0.415
	(0.0400)	(0.125)	(0.604)	(0.172)
lnresearchers	0.0126	0.371*	−0.565	0.113
	(0.0248)	(0.0776)	(0.374)	(0.106)
dcredit	0.00274*	0.0288*	0.238*	0.0184*
	(0.000656)	(0.00205)	(0.00990)	(0.00281)
lnborrow	0.0795*	0.0234	5.693*	0.578*
	(0.0244)	(0.0762)	(0.368)	(0.105)
atm	0.00498*	0.000704	−0.157*	0.0362*
	(0.000781)	(0.00244)	(0.0118)	(0.00335)
lngdppc	−0.0639*	0.124	1.569*	−0.00692
	(0.0160)	(0.0499)	(0.241)	(0.0685)
lnpop	0.0729*	−0.114*	−0.367*	0.183*
	(0.0133)	(0.0416)	(0.201)	(0.0571)
fdipercent	−0.00824*	0.0226*	−0.0493	0.00822
	(0.00155)	(0.00486)	(0.0235)	(0.00667)
trade	0.00133*	0.00180	−0.0586*	0.00272
	(0.000469)	(0.00147)	(0.00709)	(0.00201)
developdummy	0.0368*	0.0113*	0.7845*	0.0915*
	(0.0055)	(0.0024)	(0.1205)	(0.02855)
Constant	7.599*	1.658	82.78*	52.78*
	(0.325)	(1.016)	(4.905)	(1.395)
Observations	3576	3576	3576	3576
R-squared	0.100	0.135	0.436	0.156

Standard errors in parentheses.
*p < 0.01, p < 0.05, *p < 0.1.
Source: Authors' computations (2023).

The coefficient for innovation alone is 0.124 and significant at the 10% level, indicating that without adequate financial access, innovation may initially increase carbon emissions. This could be due to the resource-intensive nature of early-stage innovations. However, with sufficient financial access, there is support for developing and implementing technologies that lower emissions.

In examining entrepreneurship, the study found that financial access significantly moderates its effect on carbon emissions. The results in Model 7 of Table 7 show that the interaction term between financial access and entrepreneurship (faccess*entrep) is −0.0169 and significant at the 1% level. This indicates that financial access enhances the ability of entrepreneurial activities to reduce carbon emissions. Entrepreneurs with better access to financial resources are more likely to invest in environmentally friendly technologies and sustainable practices.

The direct impact of entrepreneurship on carbon emissions is 0.0199 and significant at the 1% level, suggesting that entrepreneurial activities alone might increase emissions. This aligns with the understanding that new business activities, especially in their early stages, can be emission-intensive. However, adequate financial access mitigates this negative impact by enabling entrepreneurs to adopt sustainable practices and technologies.

Additionally, financial access alone has a positive and significant effect on carbon emissions in both models, with coefficients of 0.170 and 0.00495, respectively. This highlights a complex relationship where financial development, if not directed towards sustainability, may lead to higher emissions due to increased economic activities. Therefore, it is crucial that financial access is channeled towards innovative and entrepreneurial activities aimed at reducing carbon emissions.

The control variables also offer insightful findings. GDP per capita (lngdppc) has a coefficient of −0.0476 and a significant impact on emissions in the first model, indicating that wealthier nations may have more resources to invest in cleaner technologies. In contrast, population growth tends to increase carbon emissions, with coefficients of 0.0191 and 0.00736, underscoring the challenge of managing environmental impacts in rapidly growing populations.

These results support the hypothesis that financial access plays a crucial moderating role in the relationship between innovation, entrepreneurship, and carbon emissions. By enhancing financial access, particularly in developing regions, it is possible to promote innovation and entrepreneurship that contribute to sustainable development. This underscores the importance of financial policies that not only drive economic growth but also ensure environmental sustainability. The study's insights provide valuable guidance for policymakers aiming to reduce global carbon emissions through strategic financial inclusion and support for innovative and entrepreneurial ventures.

4.4. Robustness checks through decomposition

4.4.1. Decomposition: effect of innovations on various entrepreneurship

To ensure the robustness of the baseline results, this study decomposes various indices to examine their individual effects, verifying the consistency of the series. Decomposition allows us to pinpoint which aspects of innovation most effectively influence entrepreneurship, providing valuable insights for policymakers on resource allocation.

The decomposition of innovation includes four components: technology export (techexport), patents, research and development export (rdexport), and the number of researchers (inresearchers). Entrepreneurship is similarly broken down into four components: new business (newbus), new business density, self-employment, and ease of doing business (easebus). The results in Models 8,9,10, and 11 of Table 9 contains the results of innovations on various aspect of entrepreneurship.

At a 1% significance level, technology export significantly impacts new business, new business density, and ease of business, with coefficients of 0.0156, 0.0602, and 0.0409 in model 8,9, and 11, respectively. This implies that higher levels of technology export correlate with improvements in these entrepreneurial components, suggesting that countries exporting technology have tested and validated its efficacy domestically. Jafari-Sadeghi et al. (2021) support this view, noting that domestic success often precedes technology export, enhancing local business environments. Interestingly, self-employment is not significantly influenced by technology export, contrary to expectations that abundant technology would boost self-employment.

Additionally, Patents significantly affect all components of entrepreneurship at a 1% significance level. A 1% increase in patents leads to increases in new business (0.0735%), new business density (0.00186%), self-employment (0.01154%), and ease of business (0.00311%). Melero et al. (2020) highlight that strong patent protection fosters control over inventions, benefiting broader aspects of society and significantly impacting entrepreneurship more than technology export.

Table 9
Decomposition of innovation and entrepreneurship on carbon emission.

VARIABLES	Decomposed innovations				Decomposed entrepreneurship			
	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
	cemission	cemission	cemission	cemission	cemission	cemission	cemission	cemission
dcredit	0.0344*	0.0285*	0.0507*	0.000335*	0.0289*	0.0326*	0.0358*	−0.0183*
	(0.00619)	(0.00591)	(0.00621)	(0.00606)	(0.00599)	(0.0068)	(0.00603)	(0.00619)
lnborrow	0.0234*	0.0249*	0.0211*	0.0232*	0.0227*	0.0233*	0.0243*	0.0114*
	(0.00238)	(0.00235)	(0.00236)	(0.00238)	(0.00237)	(0.00238)	(0.00238)	(0.00233)
atm	−0.0428	−0.0855	0.0890	−0.325	−0.897	−0.0470	0.0169	−0.0378*
	(0.00753)	(0.0744)	(0.0756)	(0.0758)	(0.0755)	(0.00753)	(0.00764)	(0.00732)
lngdppc	0.00383	0.00428*	0.0326	0.0039	0.0045*	0.00395	0.0039	0.0073*
	(0.00157)	(0.00154)	(0.0155)	(0.0016)	(0.0016)	(0.00157)	(0.00156)	(0.0015)
lnpop	0.0090*	0.00765*	0.00787*	0.00870*	0.00804*	0.00876*	0.00905*	0.00844*
	(0.00129)	(0.00127)	(0.00127)	(0.00129)	(0.00129)	(0.00129)	(0.00128)	(0.00122)
fdipercent	−0.0848	0.0465	−0.0384	−0.0591	0.0527	−0.0619	0.098	−0.0104
	(0.0152)	(0.0150)	(0.0150)	(0.00152)	(0.00152)	(0.00153)	(0.00152)	(0.00144)
trade	−0.0167	−0.0166	−0.0243	−0.1060	−0.0168	−0.0346	0.0565	−0.0121*
	(0.00459)	(0.00452)	(0.00453)	(0.0459)	(0.00458)	(0.0459)	(0.00457)	(0.00438)
developdummy	0.0172*	0.0142*	0.0253*	0.0033*	0.0144*	0.0163*	0.0179*	−0.092*
	(0.00309)	(0.00295)	(0.00310)	(0.00303)	(0.00299)	(0.0034)	(0.00301)	(0.0309)
techexport	−0.00413							
	(0.00263)							
lnpatent		−0.0104*						
		(0.00103)						
rdexp			−0.0331*					
			(0.00337)					
lnresearchers				−0.00348				
				(0.00217)				
lnnewbus					−0.00819*			
					(0.00162)			
newbusdensity						−0.000220		
						(0.000518)		
easebus							−0.0169*	
							(0.00379)	
selfemployed								−0.0207*
								(0.00102)
Constant	−0.074*	−0.146*	−0.0235	−0.0482	−0.140*	−0.0733*	0.0145	0.101*
	(0.0267)	(0.0273)	(0.0269)	(0.0311)	(0.0297)	(0.0268)	(0.0332)	(0.0268)
Observations	3576	3576	3576	3576	3576	3576	3576	3576
R-squared	0.725	0.872	0.862	0.727	0.781	0.726	0.774	0.674

Standard errors in parentheses.
*p < 0.01, p < 0.05, *p < 0.1.
Source: Authors' computations (2024).

Also, R&D export significantly influences new business density, self-employment, and ease of business, with coefficients of 0.692, 1.435, and 0.415, respectively, at a 1% significance level. Research and development are crucial for identifying market trends, enabling self-employment, increasing business density, and easing business operations. Safitri et al. (2020) emphasize the importance of research in driving successful entrepreneurial ventures.

The number of researchers significantly impacts new business density, with a unit increase in researchers leading to a 0.371 increase in new business density at a 1% significance level. This finding suggests that a higher number of researchers correlates with increased new business density.

On the other hand, domestic credit (dcredit) positively influences all components of entrepreneurship at a 1% significance level, indicating that increased credit access boosts entrepreneurial activities. Borrowing also positively impacts all entrepreneurship components except new business density at a 1% significance level, suggesting that access to borrowing enhances entrepreneurial activities. Additionally, ATMs positively influences new business and ease of business, but decreases self-employment. This indicates that increased ATM access may reduce the need or interest in self-employment.

These findings underscore the critical role of targeted financial access and specific innovation components in fostering robust entrepreneurial ecosystems. Policymakers should focus on enhancing financial access and supporting patent development and R&D to drive sustainable entrepreneurial growth.

4.4.2. The effect of the decomposition of innovation and entrepreneurship on carbon emissions

This section discusses the effects of decomposed innovation—technology export (techexport), patents, research and development export (rdexp), and researchers—on carbon emissions.

The results are provided in Model 12, 13, 14, 15, 16, 17, 18, and 19 in Table 9.

A 1% increase in patents significantly decreases carbon emissions by about 0.0104%, holding other factors constant. This finding aligns with Wang et al. (2020), who argue that investments in new technologies, both for domestic use and export, substantially impact carbon emissions.

Additionally, a unit increase in rdexp reduces carbon emissions by about 0.0331 units at a 1% significance level, highlighting the importance of robust research and development in lowering emissions. Fernández Fernández et al. (2018) support this, noting that adequate research in environmentally friendly activities significantly mitigates carbon emissions.

The second panel of Table 4.6 examines the impact of entrepreneurship on carbon emissions. All components of entrepreneurship, except for new business density, show a significantly negative relationship with carbon emissions at a 1% significance level. This indicates that entrepreneurship, when conducted sustainably, helps reduce carbon emissions. Sustainable entrepreneurship integrates environmentally friendly practices, thereby contributing to lower emissions.

These results underscore the importance of targeted innovation and sustainable entrepreneurial practices in achieving significant reductions in carbon emissions. Policymakers should focus on fostering both innovation and entrepreneurship to promote environmental sustainability.

5. Conclusion

This study, titled “Balancing Finance and Sustainability: The Impact of Financial Access on Carbon Emissions Through Innovation and Entrepreneurship in a Global Study,” examines how financial access influences carbon emissions through innovation and entrepreneurship. Using a robust dataset from 149 countries over 24 years and applying two-stage least squares (2SLS) techniques to address endogeneity, the study provides valuable insights into these relationships.

The findings indicate that financial access significantly enhances innovation and entrepreneurship, which have contrasting effects on carbon emissions. Innovation reduces emissions by driving the development of eco-friendly technologies, while entrepreneurship initially increases emissions but can mitigate its impact when coupled with sustainable financial practices. These results underscore the importance of designing financial systems that balance economic growth with environmental sustainability. Encouraging green entrepreneurship and fostering innovation through targeted financial incentives are essential steps toward achieving global sustainability goals.

However, the study has limitations. Its reliance on aggregate data may obscure regional variations in financial access and environmental policies. Moreover, sector-specific dynamics, such as differences between manufacturing and services, were not explored, potentially limiting the granularity of the findings.

Future research could address these gaps by conducting sector-specific analyses and localized studies to understand how financial access and innovation influence emissions in various industries and regions. Based on these findings, policymakers are encouraged to develop financial systems that prioritize green innovation and entrepreneurship to reduce carbon emissions while fostering sustainable economic growth.

5.1. Recommendations

1. Promote Financial Systems for Sustainability: Policymakers should design financial systems that directly incentivize green technologies and environmentally sustainable business models.
2. Expand Sustainable Financial Access: Broaden financial access, particularly in developing regions, to drive innovation and entrepreneurship, with clear guidelines to channel resources into sustainable, low-emission activities.

3. Invest in Green Innovation: Governments and financial institutions should prioritize funding for research and development in green technologies, offering grants and low-interest loans for innovations that reduce carbon emissions.
4. Foster Sustainable Entrepreneurship: Provide targeted training and tailored financial products to help entrepreneurs embed sustainability into their business models, mitigating the environmental impacts of new ventures.

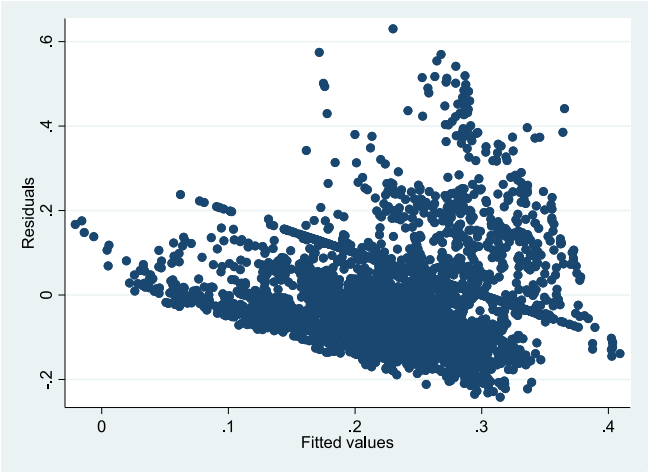
These findings underscore the critical need for financial systems that not only expand access but also actively promote green technologies and sustainable entrepreneurship, aligning economic growth with global sustainability objectives.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Appendix A. Linearity Test



Appendix B. Homoscedasticity

```
Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
---------------------------------------------------------
Ho: Constant variance
Variables: fitted values of y

    chi2(1) =     2.31
  Prob > chi2 =  0.128
```

Appendix C. Autocorrelation test

```
Wooldridge test for autocorrelation in panel data
-------------------------------------------------
H0: No first-order autocorrelation
    F(1, 49) = 1.723
    Prob > F = 0.1964
```

Appendix D. Multicollinearity test

Table 3
Variable inflation factor

	VIF	1/VIF
lnpatent	1.940	0.515
techexport	1.810	0.554
rdexp	1.660	0.601
lnresearchers	1.620	0.617
lnnewbus	1.400	0.712
newbusdensity	1.390	0.722
easebus	1.370	0.729
selfemployed	1.250	0.799
dcredit	1.220	0.820
lnborrow	1.210	0.828
atm	1.180	0.845
lngdppc	1.180	0.846
lnpop	1.140	0.875
fdipercent	1.120	0.894
trade	1.080	0.922
developdummy	1.11	0.938
	1.370	

Appendix E. Normality of Residuals test

Shapiro-Wilk W test for normal data

Variable	Obs	W	V	z	Prob>z
residuals	150	0.9818	1.153	-0.417	0.3392

Appendix F. Hausman test

Test: Ho: Difference in coefficients not systematic chi2(2) = 5.78 Prob > chi2 = 0.0163.

Appendix G. Wald Test

residuals	0.0912	0.0213	4.28	0.000	0.0492	0.1332

Data availability

Data will be made available on request.

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