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AI ADOPTION, GREEN VENTURE CAPITAL, AND ENVIRONMENTAL POLICY: EMPIRICAL INSIGHTS FROM GREEN ENTREPRENEURSHIP

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Abstract
This study investigates green entrepreneurship using an integrative framework that emphasizes environmental and economic issues in emerging and developed countries. The paper uses a quantitative research design where green entrepreneurship is the dependent variable, and the independent variables are AI adoption, renewable energy adoption, environmental taxation, green venture capital, and environmental, social, & governance practices. The study uses panel data from WDI and OECD from 2004 to 2021. The study uses an entropy measure for AI adoption. The methodology of the panel data analysis includes diagnostic tests, such as cointegration tests, correlation tests, variance inflation factor (VIF) tests, cross-sectional dependence tests, and stationarity tests. The findings show that AI adoption and ESG practices reduce green entrepreneurship, but renewable energy adoption, environmental taxation, and GVCs have a positive effect. The policy implications highlight the role of environmental regulations, the role of green finance, and technological capacity as critical to the promotion of inclusive and sustainable green development.

Keywords
Green entrepreneurship, AI adoption, ESG, green venture capital, FMOLS

1. Introduction

The escalating urgency of global climate change and resource depletion has promoted a paradigm shift towards sustainable economic models that incorporate technological advancements, financial innovation, and institutional reform (Kraus et al., 2018; Sarkodie & Strezov, 2019). The United Nations Development Program (UNDP) (Conceicao, 2024) evaluates that attaining net-zero carbon emissions by 2050 requires yearly green investments exceeding USD 4 trillion globally, emphasizing the scope of transformation needed in both developing and developed countries. Green entrepreneurship has become a vital mechanism combining sustainability and innovation, defined as the formation of ventures that combine environmental protection with economic viability (Dean & McMullen, 2007; Gast et al., 2017). Green startups advocate sustainable technologies and venture models that promote carbon neutrality, circular economy initiatives, and shared prosperity (Muñoz & Cohen, 2018; Rennings, 2000).

Artificial intelligence adoption (AI) has become a pivotal technological force shaping sustainability-focused innovation (Dwivedi et al., 2021; Rana et al., 2022). A report that artificial intelligence implementation in integrated energy systems may reduce global concern emissions by as much as 10% by 2030, increasing efficiency in energy-intensive sectors (IEA, 2023). However, renewable energy integration is important for AI to have an impact on the environment. Infrastructure for data storage and computational infrastructure is highly energy-intensive (Strubell et al., 2020). Artificial intelligence implementation fosters positive, sustainable development when integrated with renewable energy sources, digital technology, and environmental governance (Vinuesa et al., 2020). Research shows that green venture capital varies depending on policy consistency, market maturity, and institutional quality. In developed nations, venture capital markets are better integrated with environmental policy frameworks, enabling sustained green innovation cycles. In developing countries, however, the dependence on foreign funding and a lack of green financial infrastructure constrain the scalability of green ventures (Lin, 2022).

Eco-taxation, often known as environmental taxation, has become a significant fiscal tool for addressing global environmental challenges while fostering sustainable economic transformation. Conversely, in emerging countries, however, the execution of eco-taxation faces structural and socio-economic challenges, such as limited administrative capacity, dependence on resource-intensive industries, and political resistance. Globally, eco-taxation has demonstrated efficacy in diminishing greenhouse gas emissions by as much as 57.87%, while promoting eco-innovation and green patent activity (Dragicevic & Pereau, 2024; Mahmood et al., 2022). In recent years, environmental, social, and governance (ESG) standards have emerged as a fundamental criterion for organizations and investors assessing long-term sustainability and accountability. ESG refers to how organizations manage environmental sustainability, social responsibility, and corporate governance standards. These factors are presently regarded as essential for corporate reputation, financial stability, and the advancement of innovation. Governments, regulators, and investors in both developed and developing nations are progressively prioritizing ESG performance in their initiative to foster sustainable economies (Abu Afifa et al., 2025). However, while advanced countries have utilized technological advancements, robust institutions, and favorable policy frameworks to incorporate sustainability into business ecosystems, developing countries face challenges such as weak institutions, infrastructure deficits, and inadequate financing (Alwakid et al., 2021; Sun et al., 2020). Advanced economies lead in digital and artificial intelligence-driven eco-innovation, facilitating efficient resource utilization and climate risk mitigation (Galindo-Martín et al., 2020). In contrast, emerging economies have challenges such as limited research capability, insufficient technological infrastructure, and reliance on imported green technologies (Wei et al., 2023). This study examines the significant issue of how financial, institutional, and technological inequalities between developing and developed countries impact the advancement of green enterprises (Chang et al., 2024; Khan et al., 2022). It aims to evaluate the extent to which these impede environmental innovation and equitable development (Sunil & Momany, 2020). Addressing this gap is crucial for developing policy initiatives that strengthen institutional capacity, encourage green investment, and stimulate technology-driven ventures to attain global sustainability (GHERBI, 2025; Korcheva, 2023).

The rationale of this study is to understand the impact of financial, technological, and institutional aspects on green startups in advanced and emerging countries. Developed countries have benefited from resilient institutions, sophisticated innovation ecosystems, and effective legislative frameworks that promote sustainable enterprises (Mealy & Teytelboym, 2022). Conversely, emerging economies lack governance, have limited access to sustainable financing, and have technological constraints (Alwakid et al., 2021; Sun et al., 2020). This study is important as it provides an influence on sustainable enterprise. Theoretical contributions involve broadening sustainable startup enterprise theory to include institutional, technological, and fiscal aspects (Galindo-Martín et al., 2020). This study rationalizes the essential need for technological, financial, and institutional strategies to achieve global sustainability. It underscores the gap between advanced and emerging countries and necessitates coordinated legislative reforms, increased investment in green technologies, and institutional strengthening (Ovharhe & Okolo, 2022; Wei et al., 2023). Research questions of the study: (i) What is the effect of financial, institutional, and technological inequalities between developing and advanced countries on the advancement of green entrepreneurship? (ii) What significant financial, institutional, and technological inequalities between emerging and advancing economies significantly prevent environmental innovation and equitable development? (iii) What is the influence of financial, technological, and institutional factors on green ventures in developed and developing countries? (iv) What is the impact of artificial intelligence adoption, renewable energy adoption, green venture capital, eco-taxation, and ESG on sustainable enterprises?

The study is organized into the following: introduction, literature review, research methodology, data analysis, and conclusion & recommendations.

2. Literature review

2.1: Artificial intelligence adoption and green entrepreneurship

Artificial intelligence has limited green entrepreneurship due to the high financial investment costs, data infrastructure, and specialized skills that are not readily available to most green startups, especially in developing countries (Acs et al., 2018). This has limited entry and survival rates for clean ventures, particularly in emerging economies where financial and digital infrastructure is still limited (Group, 2024). There is also empirical evidence that suggests the use of AI can increase operational and environmental costs, as data centers, cloud computing, and machine learning training processes are energy-intensive, which contradicts the cost-aware and sustainability-oriented goals of green entrepreneurship (de Vries, 2023). Institutional theory argues that the misalignment of policies and regulations in AI and digitalization is the main cause of negative consequences. It explained the negative consequences in developed countries by stating that policies are more aligned with economic competitiveness rather than environmental entrepreneurship (Scharf, 2025). Innovation subsidies and AI incentives were disproportionately adopted by major ventures, while the costs of compliance for green data governance, cybersecurity, and technology standards hinder the development of green startups (Muench et al., 2022). The AI-enabled market, from this perspective, interacts with all these dynamics in reducing the incentive to pursue entrepreneurship in green sectors (Acs et al., 2018). Artificial intelligence (AI) has emerged as a technological tool in the modern digital landscape and is impacting sustainable transitions and entrepreneurial ecosystems. The implementation of AI usually leads to the creation of negative impacts on green entrepreneurship, especially in emerging economies with weak digital infrastructures and a lack of environmental awareness (Sarkodie et al., 2021).

However, according to dependency theory and the digital divide, the use of AI in developing countries has increased dependence on foreign technology, cloud computing from other countries, and foreign expertise instead of green innovation in the nation (Kwet, 2019). Research has shown that multinational corporations using AI-intensive systems have driven green enterprises in developing countries due to a lack of ability to create technology spillovers (Group, 2024). The use of AI has therefore harmed green entrepreneurship in developing countries due to increased energy intensity, increased costs of acquisition, and increased institutional inequality barriers, while reducing the potential of sustainability (de Vries, 2023). The negative environmental and entrepreneurial effects of AI proliferation have been worsened by institutional ineffectiveness and governance failure. Lack of effective environmental and ethical regulatory frameworks to govern AI development has enabled the spread of non-sustainable technologies in the developing market. Furthermore, insufficient environmental policy and the lack of effective enforcement systems have led to the introduction of AI systems that are not focused on long-term sustainability aims but instead are limited to short-term productivity benefits (Gazi et al., 2024).

H1: AI adoption negatively and significantly impacts green entrepreneurship.

2.2: Renewable energy adoption and green entrepreneurship

Green entrepreneurship has largely been the use of renewable energy resources, especially in developing countries, where sustainable development has become a burning issue. The emergence of renewable energy is related to the concept of green entrepreneurship, which can be described as the establishment of an enterprise aimed at overcoming environmental problems and maintaining economic sustainability. Clean technologies like wind, solar, and biomass energy have led to new venture opportunities among entrepreneurs by reducing the operation costs, promoting technological innovation, and creating a high level of environmental performance (Wüstenhagen & Menichetti, 2012). The rapid pace of the uptake of renewable energy has triggered the development of green startups by alleviating energy-related barriers as well as fostering eco-innovation, which proves that renewable energy is not only a supply of technology but also a strategic resource contributing to the competitive edge of environmentally oriented firms. The implementation of renewable energy (REA) has become one of the key drivers of sustainable entrepreneurship, growing environmental awareness, resource depletion, and institutional changes towards sustainability (Kraus et al., 2019).

In the past ten years, researchers have concentrated on how the shift towards renewable sources of energy such as solar, wind, biomass, and hydropower, can generate startup opportunities that anticipate environmental, social, and economic sustainability. Sustainable entrepreneurship is characterized by the ability to discover and capitalize on opportunities to create new startups that impact the environment and society through strategies (Belz & Binder, 2017). REA has a resourceful source of low-carbon and cost-effective energy and a sufficient foundation of sustainable entrepreneurship because of its enabling infrastructure for innovation (Gast et al., 2017). Environmentally conscious entrepreneurs are more poised to incorporate renewable energy technologies in their business models to reconcile profit generation and environmental stewardship (Schaltegger & Wagner, 2011).

H2: The use of renewable energy adoption has a significant and positive effect on green entrepreneurship

2.3: Environmental taxation and green entrepreneurship

Environmental taxes implemented help in the reduction of pollution and also offer the government funds to implement sustainable projects that fuel the adoption of sustainable practices that are sustainable. Entrepreneurs in developing countries often face obstacles in obtaining sufficient financing, a lack of infrastructure, and operating within a volatile market. Eco-taxation policies and other support assistance programs forced startups to devise innovations to create eco-friendly goods and services (Ekins & Speck, 2011). Taxes also influenced the behavior as it promoted the consumption of socially sustainable goods. This helped green entrepreneurs establish a sustainable market in developing nations (Coscieme et al., 2019). Researchers ascertained that stringent environmental taxation raised corporate awareness about their environmental footprint and made cleaner production more desirable, particularly when the governments related such taxes to subsidies or tax benefits for environmentally friendly startups in low- and middle-income countries (Chen et al., 2022). When the environmental taxes are used to invest in the governmental infrastructure and the business support environments, green enterprises gain greater benefits, which enhance the feasibility of entrepreneurship in the green sector. In emerging green industry countries, particularly in sub-Saharan Africa and Latin America, the environmental taxation provided an opportunity for a favorable market environment for startups in renewable energy and recycling. Highlighted that a substantial factor of environmental taxation, carbon pricing, changed the perception of both costs and benefits of various people and ventures, leading to the fact that they spend more funds on green technologies (Arogundade & Hassan, 2024).

The green startups, Asian nations, and environmental innovations are enhanced in the legislation in terms of taxes, subsidies, green education, and research funding availability (Shaikh et al., 2025a). It demonstrated that the high environmental cost and the lack of involvement of stakeholders during the transition may worsen the inequality and may hamper the involvement of the startups of small startups in the green economy (Ullah et al., 2023). Faced with a phenomenon known as tax fatigue, where a higher tax rate, especially of an unstable or problematic nature, leads to adverse consequences. Governments' transparency regarding the development of regulations and fund allocation is a significant determinant of the success of eco-taxation as a method to raise green ventures (Sadiq et al., 2022).

H3: Eco-taxation positively and significantly influences green entrepreneurship

4.4 Green venture capital and green entrepreneurship

Green venture capital (GVC) has become a growing phenomenon in recent years as a tool to contribute to sustainable entrepreneurship in developing countries. This is due to the necessity to combat climate change, environmental degradation, social inequity, and economic disparity urgently (Salaheldeen et al., 2024). The Green Entrepreneurship Ecosystems Index (GEEI) uses a dataset of 34 countries based on the years 2000 to 2019 and shows that those countries with increased levels of green venture capital and with a developed green entrepreneurship ecosystem have better economic growth, which simultaneously positively affects the environment (Singh et al., 2023). According to research involving 13 Saudi Arabian cities during the period between 2012 and 2017, green entrepreneurship, often supported by green venture capital (GVC), has a positive impact on the economy, society, and environment, and all of these impacts increase when environmental policies and institutions ensure sustainability (Alwakid et al., 2021).

Investigations on equity investment influenced by environmental policy have shown that ventures that gain access to green capital are more innovative and flexible to environmental issues. This suggests that green venture capital (GVC) emphasizes sustainability through governance by relying on investor-influenced governance frameworks (Cappellari & Gucciardi, 2024). The theoretical framework built on the theory of planned behavior was used to outline how climate-change awareness campaigns can increase the propensity of individuals to participate in environmentally friendly behaviors. The framework demonstrates how green venture capital (GVC) may support the development of entrepreneurial thought within people in the long term by involving them in meaningful initiatives within the ecosystems (Islam & Mehdi, 2024). It is empirically demonstrated that green venture capital (GVC) investments grow in policy regimes characterized by auctions of renewable energy and pricing carbon, especially in India and Brazil. The research also indicates that a 10% increase in the standards of renewable portfolios results in an average 15% increase in the green funding to the clean technology startups (Mazzucato & Semieniuk, 2018). On the contrary, the paper recognizes the reluctance in investing in clean energy startups due to inadequate profitability and consumer demand for green products. Many young startups face challenges to development and viability, even with government support. The government introduced strict policies to encourage consumer spending, but their effectiveness was limited. The regulatory framework had been inadequately designed and was limiting growth (Van den Heuvel & Popp, 2023).

H4: GVC has a positive and statistically significant effect on green entrepreneurship

2.5 Environmental, social, and governance (ESG) and green entrepreneurship

Environmental, social, and governance (ESG) frameworks were established to promote green ventures, but later empirical results show that these frameworks can create unintended obstacles to green startups (Berg et al., 2022; Christensen et al., 2022). These adverse effects are particularly salient in resource-constrained areas, where green ventures are faced with financial, institutional, and informational limitations (Amankwah-Amoah et al., 2021; Sahin et al., 2022). Small and medium enterprises, often known to be champions of green startups, do not have sufficient funds to afford sustainability reporting and certification (Grewal et al., 2019). In advanced economies, large firms leverage their established infrastructure and ESG compliance capabilities to restrict market entry for nascent ventures (Ren & Cheng, 2024). Consequently, investors will choose to commit capital to ventures that have strong and transparent ESG reporting, thus limiting the finances available to smaller green startups (Christensen et al., 2022). This capital misallocation further limits funding for early-stage sustainable enterprises (Qachach et al., 2025). The effect is magnified in low-income countries, where deficient data infrastructure and limited ESG integration exacerbate financial disparities (Harney et al., 2021).

The institutional theory and ESG frameworks have fostered conservative investor behavior and institutional inflexibility, hence further limiting startup innovation (Krueger et al., 2020). Investors who followed ESG principles valued regulatory compliance and reputational protection over high-risk innovation (Ren & Cheng, 2024). Consequently, financial resources were redirected toward stable, low-innovation enterprises, which restricted investment in clean emerging technologies (Krueger et al., 2020). The negative aspects inherent to environmental, social, and governance structures, such as elevated costs, inconsistent data, caution investors, and weak governance, diminish the financial and organizational resources required for sustainable ventures (Berg et al., 2022).

H5: ESG significantly and negatively affects green entrepreneurship

The escalating urgency of global climate change and resource depletion requires a transition toward sustainable economic strategies (Neumann, 2022). Green startups are known as an essential tool that can enable combining environmental protection with economic sustainability (Wei et al., 2023). However, there remains a significant research gap on how developed and developing countries can continue to have inherent and enduring disparities in their ability to facilitate green projects and attain sustainable development (Sunil & Momany, 2020). The literature lacks a fully integrated framework that rigorously examines how interrelated financial, institutional, and technological factors contribute to this discrepancy and the hindrance of sustainable green growth in various economies (Amini Sedeh et al., 2022).

Developed economies have strong and stable financial markets, well-established financial institutions, and vibrant green venture capital that actively promotes sustainable solutions. Green innovation is fostered by these countries through favorable regulatory structures, environmental taxation policies, and consumer cognition (Cappellari & Gucciardi, 2024; Cumming et al., 2016). Green venture capital (GVC) is a critical accelerator that offers financial support, management skills, and long-term sustainability (Bocken et al., 2014). However, in contrast, developing economies face severe impediments to green venture funding because of inadequate financial markets, limited technological capacity, increased risk of investments, and a lack of institutional support (Demirel et al., 2019).

3. Research methodology

3.1 Operationalization of the variables

Green entrepreneurship is the outcome variable of the study. Artificial intelligence adoption, renewable energy adoption, eco-taxation, green venture capital, and environmental, social, and governance (ESG) are antecedent variables. Green technological innovation is the intervening variable. Environmental policy is the moderator. Green entrepreneurship is proxied by the total number of patents of environmentally related technologies (Susantiningrum & Rapih, 2025). Artificial intelligence adoption is measured by the AI index (Sun et al., 2023). The renewable energy adoption is proxied by renewable energy consumption (% of total energy (Cetin et al., 2025). Environmental taxation is measured by the % of environmental taxes to total taxes (Shaikh et al., 2025b). Green venture capital is measured by the GVC index (Sui et al., 2025). ESG performance is measured by the ESG index (Diaye et al., 2022). Green technological innovation is proxied by medium (% manufactured exports and high-tech exports (Ullah & Shaheen, 2024). Environmental policy is measured by the environmental policy stringency index (Zheng et al., 2025).

3.2 Sample selection, data collection, and limitations

The sample was selected from 200 developing and developed economies. We eliminated 70 nations with missing data for over 5 years in green ventures. Then, we drop 57 countries due to not finding information in the OECD and WDI databases. The sample covers panel data of 73 developing and developed economies from 2004 to 2021. This study covers 18 years. The data was collected from the WDI and OECD.

Data constraints minimize the sample from 200 to 73 economies because of missing data in OECD and WDI, introducing a potential sampling bias favoring sophisticated economies, hence constraining generalizability to the least developed economies. Green entrepreneurship is proxied through environmentally related technology patents, a standardized metric that preferentially benefits large, technologically advanced corporations while neglecting smaller ventures. The time span of the study, 2004-2021, and data consistency are core limitations; this period ends before the rapid global adoption of artificial intelligence, which began after 2022. Although composite institutional indices facilitate extensive cross-country comparisons, they may overstate policy efficiency in emerging economies where written regulations often differ from actual implementation.

3.3 Entropy-weighted method

We used the entropy-weighted method to measure AI. The normalized buildup function (Yij) for the efficiency type is expressed in the following equation.

$$Yij = \frac{X_{ij}-(X_{ij})min}{(X_{ij})max-(X_{ij})min} \dots (1)$$

Gorgij et al. (2017) and Li et al. (2012) Both suggest standardizing measurement. Here is the formula for yij, which shows the AI of the ith index in the jth sample (1):

$$P_{ij} = {Yij}\Big/{\sum_{i=1}^{z} Y_{ij}} \dots (2)$$

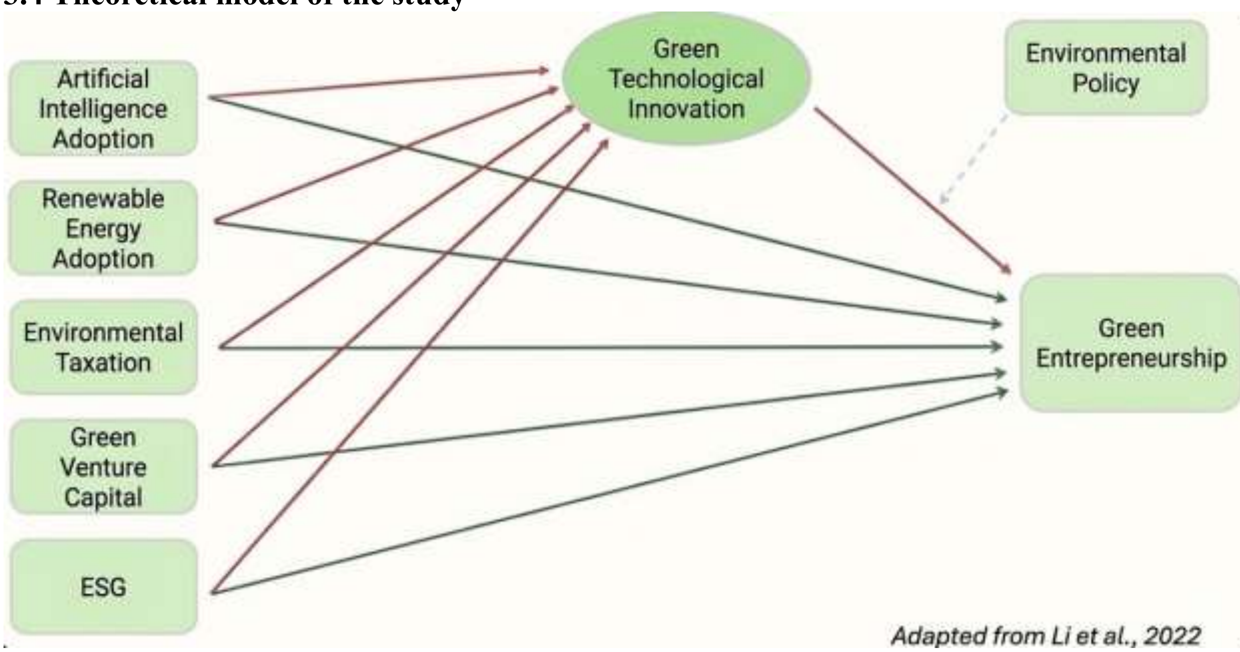
In the entropy-weighted method, the entropy value calculated for the ith index, denoted as Ei, is clearly specified as:

$$E_j = \left(\frac{1}{lnZ}\right) \times \sum_{i=1}^{z} lnP_{ij} \times P_{ij} \dots (3)$$

When pij equals zero, the EWM estimator automatically assigns InPij*Pij = 0 to facilitate the calculation. The entropy value is frequently between zero and one. Amiri et al. (2014) and Liu et al. (2010) state the EWM weight wi, in the calculation tool.

$$W_j = {(1 - E_j)}\Big/{\sum_{j=1}^{t} 1 - E_j} \dots (4)$$

3.4 Theoretical model of the study



3.5 Research hypothesis

H1: Artificial intelligence has a negative and significant effect on GE.

H2: REA is significantly positively associated with GE

H3: Eco-taxation significantly affects GE.

H4: GVC has a significantly positive impact on GE

H5: ESG has a negative and significant impact on GE

H6: The effects of the adoption of artificial intelligence, the adoption of renewable energy, eco-taxation, and ESG on green entrepreneurship are mediated by green technological innovation.

H7: The effects of artificial intelligence adoption, renewable energy adoption, eco-taxation, and ESG on GE are moderated by environmental policy.

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3.6 Empirical models of the study
3.6.1 Base model

$$GE = \beta 0 + \beta 1AIA + \beta 2REA, + \beta 3ENT + \beta 4GVC + \beta 5ESG + \epsilon$$

3.6.2 Mediation model

$$GE = \beta 0 + \beta 1AIA + \beta 2\text{REA} + \beta 3ENT + \beta 4GVC + \beta 5ESG + \beta 6GTI + \epsilon$$

3.6.3 Moderation model

$$GE = \beta 0 + \beta 1AIA + \beta 2\text{REA} + \beta 3ENT + \beta 4GVC + \beta 5ESG + \beta 6GTI + \beta 7(IVs * EP) + \epsilon$$

Analysis of data
4.1 Descriptive statistics

Table 2 presents descriptive statistics results. The sample data estimates show that the means of green entrepreneurship, artificial intelligence adoption, renewable energy adoption, environmental taxation, green venture capital, ESG, green technological innovation, and environmental policy are 1.406, 0.314, 3.486, 0.809, 0.652, 0.41, 3.664, and 2.312, respectively. These are the mean values reflecting the central tendency of each of the respective coefficients of the empirical data. The range is between a minimum of 0 and a maximum of 7.946.

Table 2: Descriptive statistics

Variable	Obs	Average	Std. Dev.	Min	Max
GE	1314	1.406	1.104	0.002	4.421
AIA	1314	0.314	0.161	0.002	0.717
REA	1314	3.486	1.217	0.152	5.996
ENT	1314	0.809	0.486	0.003	2.099
GVC	1314	0.652	0.531	0	1.693
ESG	1314	0.41	0.334	0.003	1.468
GTI	1314	3.664	0.684	1.04	4.732
EPS	1314	2.312	1.954	0.031	7.946
PG	1314	1.554	1.569	0	21.7
LL	1314	1.432	0.084	1.204	1.527
GDP	1314	2.159	0.167	1.713	2.5

Source: Authors p<0.01***, p<0.05**, p<0.1*

4.2 VIF and correlation matrix

Table 3 shows the results of the variance inflation factor (VIF) and correlation matrix. According to Table 3, the VIFs are all below 5, thus indicating that there is no multicollinearity between independent variables AI, REA, ENT, GVC, and ESG. A multicollinearity phenomenon, which occurs when independent variables are interconnected, is identified using the VIF (Montgomery et al., 2021). The results of correlation analysis show that renewable energy adoption, environmental taxation, green venture capital, ESG, green technological innovation, and environmental policy correlate positively with GE, and artificial intelligence adoption correlates negatively. The results support the formation of a statistically strong model that is not multicollinear.

Table 3: VIF and correlation matrix

Variables	VIF	GE	AIA	REA	ENT	GVC	ESG	GTI	EPS
GE		1							
AIA	1.06	-0.118***	1						
REA	1.04	0.124***	0.002*	1					
ENT	1.03	0.157***	-0.039*	0.035*	1				
GVC	1.08	0.126***	-0.20***	0.103***	0.091***	1			
ESG	1.05	0.116***	-0.07***	0.039*	0.037*	0.124***	1		
GTI	1.1	0.127***	0.082***	0.150***	0.100***	-0.024*	0.144***	1	
EPS	1.06	0.115***	0.083***	0.070***	0.120***	0.001*	-0.048*	0.195***	1

Source: Authors p<0.01***, p<0.05**, p<0.1*

4.3 Cross-sectional dependency test (CSD)

These are a common occurrence in panel data analyses, where samples are pooled in several countries or cross-sections (Pesaran, 2021).

Table 4: CSD results

Variable	CD-test	p-value	mean joint T	average ρ	average abs(ρ)
GE	1.443	0.149	18	0.01	0.2
AI	19.463	0.000	18	0.09	0.26
REA	-1.861	0.063	18	-0.01	0.2
ENT	1.052	0.293	18	0.00	0.2
GVC	20.387	0.000	18	0.09	0.28
ESG	-1.922	0.055	18	-0.01	0.27

Source: Authors p<0.01***, p<0.05**, p<0.1*

The statistic obtained with green entrepreneurship is equal to 1.443, indicating a relatively low cross-sectional dependence of the observations. However, the p-value shows that dependency is statistically significant. The average joint dependency among variables is 18, which suggests that on average the sample has 18 cross-sections. Adoption of AI is highly significant, as is green venture capital (GVC). Renewable energy adoption and ESG are also significant. AI adoption, renewable energy adoption, environmental taxation, green venture capital, and ESG statistics are

19.463, -18.61, 1.052, 20.387, and -1.922, respectively. Finally, the table of cross-sectional dependency tests shows that all the variables in the model are significantly interdependent except for two. The 20.387 and 19.463 of the CD tests of green venture capital and AI with the p-value of 0.000 identify the presence of strong cross-sectional dependence.

4.4 Slope of homogeneity results

The slope homogeneity test results show the slope of two groups. The Δ statistic of the 1st group is 3.747, and the p-value is 0.000, which means that the difference in slopes is statistically significant. Further, the adjusted Δ value increases to 4.793, which still has a p-value of 0.000. The second group has a Δ of 9.718 and a p-value of 0.000; this implies the slope difference is highly significant. The adjusted Δ statistic also increases in value to 12.431, which is also accompanied by a p-value of 0.000.

Table 5: Slope of homogeneity

Tests	Statistics	p-value
First-group		
Δ	3.747	0.000
Adj Δ	4.793	0.000
2nd-group		
Δ	9.718	0.000
Adj Δ	12.431	0.000

4.5 Panel unit root test

Variable	CADF		CIPS	
	I (0)	I (1)	I (0)	I (1)
GE	-3.662***	/	-3.662***	/
AI	-3.652***	/	-3.652***	/
REA	-3.773***	/	-3.773***	/
ENT	-3.832***	/	-3.832***	/
GVC	-3.683***	/	-3.683***	/
ESG	-2.287***	/	-2.287***	/
GTI	-2.886***	/	-2.886***	/
EPS	-2.989***	/	-2.989***	/

Table 6: 2nd generation unit root results

The CADF value of variable GE is -3.662, and it is stationary. CADF statistics of -3.652, -3.773, -3.832, -3.683, -2.287, -2.886, and -2.989 of AI, REA, ENT, GVC, ESG, GTI, and EPS, respectively, indicate stationary and statistically significant. As a result, all these variables are at the equilibrium level, and I = 0.

4.6 Co-integration test

The analysis indicates that the panel variables have a strong long-term relationship. Pedroni cointegration can be evaluated using a variety of diagnostic tests; one of them is the M. Phillips-P-t statistic, which has a value of 10.8059 and a p-value of 0.000. Moreover, the presence of cointegration is supported by the P.-Perron test with a value of -15.8918 and a p-value of 0.000. A. D.-Fuller test with a value of -14.4934 and a p-value of 0.000. The Kao test is as follows: M.D.-Fuller-t, D-Fuller-t, A. D.-Fuller-t, Unadjusted M.D.-test, and Unadjusted D.-Fuller-test values are -5.3724, -14.6703, -7.3656, -37.1058, and -28.4981, respectively; all values are statistically significant.

Table 7: Cointegration results

Pedroni test	Statistics	p-value	Decision
M. Phillip–Perron t	10.8059	0.000	Cointegration exist
P.–Perron t	-15.8918	0.000	Cointegration exist
A. Dickey–Fuller t	-14.4934	0.000	Cointegration exist
Kao test			
M. D.–Fuller t	-5.3724	0.000	Cointegration exist
Dickey–Fuller t	-14.6703	0.000	Cointegration exist
A. D.–Fuller t	-7.3656	0.000	Cointegration exist
Unadjusted M. D.–Fuller t	-37.1058	0.000	Cointegration exist
Unadjusted D.–Fuller t	-28.4981	0.000	Cointegration exist

Source: Authors p<0.01***, p<0.05**, p<0.1*

4.7 Generalized method of moments (GMM)

4.7.1 GMM with mediation

The lagged dependent variable L.GE has coefficient estimates of -0.189 and -0.148, both statistically significant and negative. Moreover, the influence of artificial intelligence adoption can also be estimated by the coefficient values of -0.706 and -0.607, both of which are significant and harm green ventures. The coefficient estimates of renewable energy adoption, environmental taxation, and green venture capital are 0.134, 0.160, 0.129, -0.066, 0.153, & 0.0857, which are positive and statistically significant. The coefficient estimates of ESG, -0.485 and -0.455, are negative and significantly impact green ventures. Lastly, the integration of green technological innovation (GTI) as a mediator has a significant and negative impact on the green ventures.

Table 8: GMM without and with mediation

Variables	GE	GE
L.GE	-0.189***	-0.148***
	(-0.0367)	(-0.0284)
AI	-0.706***	-0.607***
	(-0.204)	(-0.197)
REA	0.134***	0.160***
	(-0.022)	(-0.0283)
ENT	0.129***	-0.066
	(-0.0276)	(-0.0948)
GVC	0.153**	0.0857

	(-0.0741)	(-0.0801)
ESG	-0.485***	-0.455***
	(-0.0889)	(-0.133)
GTI		-0.556***
		(-0.126)
Observations	1,168	1,168
Number of id	73	73

Source: Authors *p<0.01***, p<0.05**, p<0.1**

4.8 Moderation

First, the lagged variable L.GE shows a significant but negative correlation with green venture value of -0.142. Table 9: Moderation results

VARIABLES	GE
L.GE	-0.142***
	(-0.0085)
AI_EPS	-0.254***
	(-0.00871)
REA_EPS	0.0141***
	(-0.00199)
ENT_EPS	-0.0149***
	(-0.00369)
GVC_EPS	0.0319***
	(-0.00992)
ESG_EPS	0.0935***
	(-0.00568)
Observations	1,168
Number of id	73

Source: Authors **** p<.01, ** p<.05, * p<.1*

Similarly, the adoption of artificial intelligence and environmental taxation has negative and significant coefficients of -0.254 and -0.0149, respectively. Conversely, renewable energy adoption, green venture capital, and ESG values of 0.0141, 0.0319, and 0.0935 are statistically significant and positive on green entrepreneurship. The results show the high cost, lack of skills, and integration challenges in the developing economies, which hinder the development of green ventures (Boonmee et al., 2025).

4.9 Quantile regression

The empirical results show that artificial intelligence has a consistently negative effect on all four quantiles, and the estimated relationships with the dependent variable GE are -0.183, -0.248, -0.244, and -0.396 at the 0.4, 0.45, 0.5, and 0.55 quantiles, respectively. Conversely, the adoption of renewable energy shows a strong and statistically positive impact with values of 0.0375, 0.0452, 0.0491, and 0.0525 at quantiles of 0.4, 0.45, 0.5, and 0.55, respectively. In environmental taxation, green venture capital, and ESG indicators also demonstrate positive and statistically significant results at all quantiles. ENT, GVC, and ESG 0.319, 0.332, 0.327, 0.314, 0.0914, 0.107, 0.124, 0.113, 0.129, 0.156, 0.176, and 0.144 are statistically significant and positive at quantiles 0.4, 0.45, 0.5, and 0.55.

Table 10: Quantile regression

VARIABLES	0.4	0.45	0.5	0.55
AI	-0.183**	-0.248**	-0.244**	-0.396***
	(-0.0917)	(-0.0965)	(-0.105)	(-0.128)
REA	0.0375***	0.0452***	0.0491***	0.0524***
	(-0.0119)	(-0.0126)	(-0.0137)	(-0.0167)
ENT	0.319***	0.332***	0.327***	0.314***
	(-0.0298)	(-0.0314)	(-0.0342)	(-0.0418)
GVC	0.0914***	0.107***	0.124***	0.113***
	(-0.0282)	(-0.0297)	(-0.0323)	(-0.0395)
ESG	0.129***	0.156***	0.176***	0.144**
	(-0.0436)	(-0.0459)	(-0.0501)	(-0.0612)
Constant	0.386***	0.403***	0.424***	0.560***
	(-0.0619)	(-0.0652)	(-0.071)	(-0.0867)
Observations	1,314	1,314	1,314	1,314

Source: Authors *p<0.01***, p<0.05**, p<0.1**

4.10 Fully Modified Ordinary Least Squares (FMOLS)

The fully modified ordinary least squares (FMOLS) estimator is commonly used to estimate long-run parameters in the presence of cointegration, which is effective in preventing the serial correlation and endogeneity issues (Phillips & Hansen, 1990). It can support heterogeneous cointegrating vectors in a dynamic panel model, thus converging to cross-sectional heterogeneity in recent panel root and cointegration (Hamit-Haggar, 2012). A growth of green ventures by 0.17937 units is related to an increase in the adoption of artificial intelligence, with an insignificant reporting level of 0.3211.

Table 11: Panel Fully Modified Least Squares (FMOLS) results

Variables	Statistics	St. Error	t-values	Sig
AI	0.17937	0.265918	0.992599	0.3211
REN	0.190668	0.033383	8.714233	***
ENT	0.435061	0.100533	6.699298	***
GVC	0.23058	0.081498	3.657652	***
ESG	0.443657	0.123802	4.51862	****
R-squared	0.030785	Mean dependent var		1.40143
Adjusted R-squared	0.027649	S.D. dependent var		1.104577
S.E. of regression	1.0892	Sum squared resid		1015.717

Long-run variance	1.388563

Source: Authors $p<0.01$***, $p<0.05$**, $p<0.1$*

4.11 FMOLS results with inclusion of mediator (green technological innovation)

4.12 FMOLS results with inclusion of mediator

Variables	Statistics	Std.Error	t-values	Sig
AI	-0.343177	0.204116	-1.68129	*
REN	0.105854	0.026684	3.966978	***
ENT	0.295052	0.069352	4.254387	***
GVC	0.204397	0.063486	3.219558	***
ESG	0.321829	0.102386	3.143277	***
GTI	0.17532	0.034161	5.132249	***
R-squared	0.066926	Mean dependent var		1.390351
Adjusted R-squared	0.063096	S.D. dependent var		1.100934
S.E. of regression	1.065636	Sum squared resid		1383.136
Long-run variance	1.364592			

Source: Authors *** $p<.01$, ** $p<.05$, * $p<.1$

The coefficients explain the impact of each independent variable on the dependent variable of green entrepreneurship. The coefficient of artificial intelligence is -0.3431, which states that when artificial intelligence (AI) increases, the decline of green venture activity is -0.3431. The adoption of renewable energy also seems to be positively and significantly associated with green entrepreneurship value, which is -0.3431 with a p-value of 0.000. ENT, GVC, ESG, and GTI values are 0.2950, 0.2043, 0.3218, and 0.1732 with a p-value of 0.000. Mediator green technological innovation mediates positively and significantly.

4.12 Dynamic Ordinary Least Squares (DOLS)

DOLS is often suggested as the estimator for estimating long-run relationships between cointegrated variables due to its ability to provide accurate and unbiased estimates that address endogeneity and correlation (Stock & Watson, 1993). The estimated coefficient of the AI value is 0.2424, but the p-value is 0.3622, which shows that this coefficient is not significant. The adoption of renewable energy has a statistically significant and positive coefficient of 0.1837 and a p-value of 0.000. ENT, GVC, and ESG values are 0.4113, 0.2483, and 0.4519, which are also statistically significant. The strongest and most positive impact has been observed with the ESG performance on green ventures, with a coefficient of 0.4519 and a p-value of 0.000.

Table 13: Results (DOLS)

Variables	Statistics	St. Error	t-values	Sig
AI	0.242438	0.265918	0.911701	0.3622
REN	0.18374	0.033383	5.503963	***
ENT	0.411371	0.100533	4.091895	***
GVC	0.24837	0.081498	3.047565	***

ESG	0.451912	0.123802	3.650294	***
R-squared	0.328635	Mean dependent var		1.40143
Adjusted R-squared	0.044211	S.D. dependent var		1.104577
S.E. of regression	1.079884	Sum squared resid		1015.717
Long-run variance	1.158795			

Source: Authors *** *p<.01,* ** *p<.05,* * *p<.1*

5. Conclusion and recommendations

The study examines the interrelationships between the adoption of artificial intelligence, renewable energy adoption, eco-taxation, and environmental, social, and governance factors on green entrepreneurship in 73 emergent and developed economies between 2004 and 2021 using the Generalized Method of Moments (GMM), specifically the dynamic threshold model that supports endogeneity. The FMOLS and DOLS tests are used to determine the mediating and moderating impacts.

The study explores the interdependence of artificial intelligence, adoption of renewable energy, green venture capital, eco-taxation, and environmental, social, and governance factors on the effect on green entrepreneurship using the Generalized Method of Moments, specifically the dynamic threshold model, which is endogeneity-loving, to investigate a sample of seventy-three emergent and developed states between 2004 and 2021. They used econometric tests (FMOLS and DOLS) that yielded subtle information on short-run and long-run dynamics and the mediating and moderating impacts. The empirical studies across the board supported the fact that the adoption of renewable energy and the imposition of environmental taxes have a positive impact on green ventures. Such variables promote cleaner production, reduce pollution, and trigger a green economic revolution, and so supporting sustainable enterprises, supportive regulatory frameworks, and availability of resources plays a crucial role. In its turn, the effect of the adoption of AI on green ventures is often negative. The discussion repeatedly revealed that the increased adoption of AI may severely hinder the process of green entrepreneurship, particularly in developing economies, mainly because of the high costs involved in implementation, low rates in most countries, lack of appropriate skills, and inadequate infrastructure. It means that the benefits of AI adoption are not self-evident and, when not planned strategically in relation to renewable energy and strong governance, can increase environmental problems. It is important to note that the outcomes of GMM also suggest that the adoption of AI in the past has harmed green entrepreneurship due to high costs and marginal adoption, which is always an impediment to using AI as a means of bringing about sustainable results in specific settings. Green technological innovation (GTI) also manifests similar negative effects on green entrepreneurship. Green venture capital and ESG performance have been found to have a big positive impact on green ventures in the long term. Green venture capital fulfills the necessary financial resources and experience, and strict ESG policies increase the long-term outcomes with higher efficiency and investor trust. However, it is also important to understand that the ESG regulation can pose a problem to resource-deprived startups, especially in developing countries, as a result of increased compliance and data discrepancies. The role of green technological innovation is an advantageous and remarkable mediator and thus enhances the positive influences of these variables on green entrepreneurship. The prevalent challenges that are faced by emerging economies include poor affordability of innovation, poor institutions, lack of access to green finance, and poor technological infrastructure that hinder efficient application and accrual of good technologies and policy tools. Moderation outcomes also show that strict environmental policy enhances the weight of critical effects of financial and governance variables, which highlights the significant importance of favorable regulatory conditions to convert policy commitment to the growth of entrepreneurship.

The best way researchers can enhance the knowledge on green startups and their multi-faceted drivers is through longitudinal and cross-country comparative studies to establish the dynamic association between technological, financial, and policy variables. Given the complexity of the relationships among artificial intelligence, renewable energy adoption, green venture capital, eco-taxation, and ESGs, researchers should employ complex methodological techniques, including system dynamics and machine learning, to evaluate mediating and moderating variables. In addition, it is urgent to explore industry-related metrics, especially in developing countries where technical and regulatory differences pose their own challenges. Empirical research should focus on contextual aspects that determine the adoption and effectiveness of AI and renewable energy technologies, considering socio-economic, institutional, and infrastructural aspects. The mediating effect of green technological innovation ought to be considered in future studies to determine its ability to augment or buffer the impact of financial and policy tools on the success of green startups. Academic and research institutions are critical in the promotion of innovation and the expansion of capabilities. Their priority must be the development of specialized curricula and training workshops that will equip students and firms with AI, renewable energy adoption, and sustainable venture practice skills. Entrepreneurship to promote interdisciplinary cooperation and knowledge sharing and create empirical data to support policy and practice can be boosted by creating research centers with an emphasis on green innovation. The institutions should encourage industry and academic partnerships to bridge the technology-to-commercialization gap, particularly in economies where technological and financial obstacles are becoming more pronounced. Green innovation pilot projects, green innovation incubators, and green innovation accelerators may offer essential training, funds, and market networks. The institutions are supposed to promote the integration of ESG principles into their operational models to promote the culture of responsible innovation and sustainability. Ease of access to financing institutions can reduce funding access gaps and technical uptake by simplifying funding mechanisms, such as grants, subsidies, and green venture capital funds.

The policymakers need to ensure an environment that encourages the growth of green startups through holistic, specific, and progressive policies. Governments with comprehensive strategies that include financial rewards, technology, and regulatory measures to promote sustainable venture growth. Creating green venture capital funds and other financial instruments, including green bonds and subsidies, can significantly enhance access to capital for startups involved in renewable energy and environmentally friendly industries. The policymakers ought to automate the regulatory processes, minimize the bureaucratic barriers, and provide financial incentives to support the development and growth of green ventures. A high level of environmental policies and long-term climate commitments will bring about stability and predictability, thus encouraging ventures and investors to invest in sustainable endeavors.

The dataset spans the years 2004-2021, and thus the recent wave of artificial intelligence holds a variety of implications for green entrepreneurship. Moreover, the data available for emerging economies was not sufficient, which may pose challenges to the generalizability of the findings. Finally, the complex interdependencies among the variables make it difficult to identify the specific impact of each factor on the performance and development of green startups, including ESG frameworks, the transition to renewable sources, environmental taxation, and technology integration.

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Table 1: Description of variables

Dependent Variables	Notation	Indicators	Data sources
Green Entrepreneurship	GE	Total patents of environmentally related technologies	OECD
Independent Variables			
Artificial Intelligence	AI	Appendix 1	IFR, WIPO, UNCTAD, WDI, WEF, WB
Renewable energy adoption	REA	Renewable energy consumption (% of total energy)	WDI
Environmental taxation	ENT	% of ecological taxes to total taxes	OECD
Green venture capital index	GVC	Growth rate of venture capital (%)	OECD
		Seed and start-up stage venture capital /GDP (%)	OECD
		Later stage venture capital /GDP (%)	OECD
		Total venture capital /GDP (%)	OECD
Environmental, social, and governance	ESG	Appendix 2	WDI
Mediator			
Green technological innovation	GTI	Medium and high-tech exports (% of manufactured exports)	WDI
Moderator			
Environmental policy index	EP	Environment policy stringency index	OECD
Control variables			
Population Growth	PG	% Annual Growth of Population	WDI
Literacy level	LL	Literacy rate, adult total (% of people ages 15 and above)	WDI

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GDP	GDP	GDP per capita (constant 2015 US$)	WDI

Source: Authors

Appendix 1: AI Index

Indicator	*Basic Indicator*	*Source*
AI-related technology	Industrial robotics-supply chain	IFR
	Patents covering artificial intelligence	WIPO
	Indicates the application of frontier technology	UNCTAD
Network infrastructure	Access to bandwidth per 100 people (fixed)	WDI
	Fixed telecommunication lines per 100 people	WDI
	% of people using internet	WDI
	Web server per 10000 people secured	WDI
International competitiveness of digital products	High-tech product	WDI
	Information and communication technology goods export in %.	WDI
	Share of information and communications technology service export	WDI
Government institutional support	Business Environment Index	WBR
	Intellectual Property Protection	World Economic Forum
	Electronic participation	UN e-government survey
	online service	UN e-government survey

Source: Authors

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Appendix 2: ESG

Dimension		*Measurement*	*Data Source*
Environmental	Air quality assessment	Control of air pollution	WDI
	Water Resources Management and Sanitation	waste-water treatment	WDI
	Forest Resource Management	Forest area (%)	WDI
	Renewable Energies Production	Incineration of renewable energy and waste energy	WDI
		Production of renewable energy	WDI
		Use of renewable energy	WDI
Social	Human Capital Development	Secondary school enrolment	WDI
	Demographic Analysis	Life expectancy	WDI
	Public Health Issues	Public health expenditure	WDI
	Employment Dynamics	Cumulative workforce of non-vulnerable employees	WDI
	Gender Equality and Equity	Women to male labour participation ratio	WDI
		Gender parity index	WDI
Governance	Democratic Institutional Structures	Control of corruption	WDI
		Rule of law	WDI
		The voice and accountability measure	WDI
	Safety Policy enactment	The country effectiveness measure	WDI
		The political stability measure	WDI
		Quality of regulatory measure	WDI

Source: Authors