IJBB
International Journal of Biotechnology and Biomedicine
Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

Pathways to Sustainable Agriculture in Emerging Markets: Firm-Level Evidence

Sania Asad[1], * Amiya Bhaumik[1]

[1]Department of Business and Accountancy, Lincoln University College, Malaysia

***Corresponding Author's e-mail**: saniaasad51@gmail.com

Article received on 10th January 2026.
Accepted on 4th February 2026.

Abstract
In order to achieve climate resilience and food security by 2030, the transition towards sustainable and regenerative food systems is critical, yet firm-level evidence investigating the drivers of sustainable agriculture is missing in emerging economies. The study investigates the impact of green finance and technological advancement, sustainability performance and firm growth opportunities. The study investigates a balanced dataset of Agri-filled firms listed on the Pakistan Stock Exchange. The study allocates fixed-effects panel regression and mediation analysis, predicting that technological advancement has a statistically strong and positive impact on sustainable performance. However, green finance possesses no direct impact. Sustainability performance exerts a significant positive impact on firm growth. The mediation analysis predicts that sustainability performance fully transmitted effects of technological advancement on firm growth, whereas green finance has no effect at all on firm growth in the presence of sustainability performance as a mediator. The insignificance of green finance suggests that green-labelled financial resources do not necessarily translate into regenerative practices in agriculture domain, likely due to weak operational integration, lack of infrastructure, institutional barriers and limited absorptive capacity. These findings also highlight the importance of the Climate Smart Agriculture Framework, as climate-smart technologies lay out the basis for sustainability practices for regenerative agriculture. The study is highly effective for policy insights, emphasizing that green financial instruments alone are not enough to create climate-resilient and equitable food systems. However, investments in digital farming, Agri- based technological advancement and agricultural innovation could produce a more effective approach for climate resilience.

Keywords: Green Finance; Climate Resilience; Technological Advancement; Equitable Food Systems; Sustainability Performance

1.0 Introduction

According to the literature on sustainability transition, financial resources and technological advancements collectively posit the adoption of sustainable practices. Environmentally beneficial investments are identified as a vehicle for green financing to facilitate environmentally beneficial investments and low-carbon transitions. At both macro-economic and sector level, green finance has significantly contributed towards environmental outcomes

Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

and productivity gains through structural transformation and innovation. The Chinese agriculture industry is a primary example of reducing greenhouse emissions utilizing green finance practices (Mo *et al.*, 2024). Green productivity outcome is also a by-product of green financing (Lee *et al.*, 2022). Structural Upgrades and Technological advancement can also be correlated with enhanced green total factor productivity (Chu *et al.*, 2024).

However, it is evident that green financing necessarily does not result in better regenerative outcomes and sustainability outcomes at the farm level. Several issues in emerging markets, such as poor monitoring, limited absorption capacity, misalignment of financing mechanisms, institutional barriers, and lack of education in the agricultural field, are the main reasons for inequitable food systems and unfair access for marginalized communities. Although Pakistan's sustainability framework is developing and demonstrates significant policy interventions and commitment to a sustainable future, there are huge barriers in mobilizing and directing capital towards sustainable outcomes (Ministry of Climate Change, 2023; UNDP Pakistan, 2022).

While green financing is extremely important and significant in promoting climate-resilient agriculture, technological advancement in the field of agriculture, constituting climate-smart and digitally-enabled solutions, is of extreme significance to enhance resilience and adaptation in the agriculture domain. Climate Smart Agriculture (CSA) is a combination of productivity, adaption and mitigation pillars. Precision agriculture, digital advisory services, improved irrigation and resource efficiency are the core elements of the Climate Smart Agriculture Paradigm (Sultan *et al.*, 2022; World Bank, 2019). Although the rate of CSA adoption is driven by local conditions and institutional environment, various studies across different regimes acknowledge that technology can play a vital role in building resilience (Asad *et al*., 2025).

In the context of this disposition, practical questions taken into consideration for this study include: do green finance and technological advances improve sustainability performance? Does sustainability performance lead to enhanced growth and resilience outcomes in the agri-food value chain? In this study, we have employed firm-level panel data collected through agri-food value chain firms in Pakistan. This study demonstrates that technological advances are a primary source of sustainability performance in the agricultural domain. Sustainability performance contributes to fair food systems, creating value chain inclusivity for marginalized communities. This study claims that sustainable performance is a proxy for governance and regenerative practices responsible for water and soil biodiversity. To inform learning outcomes across the countries, this study indicates findings that align with global literature of green finance and Climate Smart Agriculture. This study is instrumental for providing guidance for financial institutions, agri-business, stakeholders, policy makers, and educational institutes, highlighting that their investments in conscious financial practices and technological acquisitions could produce sustainable, resilient outcomes.

2.0 Literature Review

2.1 Green Finance and Sustainability Transitions in Agriculture:

The term green finance refers to the flow of funds, investments, financial instruments (loans, bonds etc.), and credit towards the projects that produce environmental outcomes, sustainability transitions and mitigate climate risks. Increased productive efficiency and enhanced sustainability outcomes are results of green financing in agriculture. However, this relationship is dependent upon the location and other various mechanisms, where green finance practice is being carried out. Mo *et al.* (2023) indicated that structural modernization and

Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

technological advancements in the agricultural domain contribute highly towards sustainable agricultural development.

Agricultural green total productivity can be enhanced indirectly by means of green financing carried out through industrial structure upgrades, technological advancement and optimized energy consumption (Chu *et al.*, 2024). Green finance can also improve an organization's environmental-economic performance. However, the effectiveness of this financing technique completely depends upon strong evidence, good monitoring, ability of an organization to create tangible change through mobilizing green funds (Lee *et al.*, 2022). Emerging economies like Pakistan are progressing in their agenda of a sustainable finance framework due to accurate policy-making and a developed taxonomy. Yet, it seems difficult to observe the impact of policy due to a lack of institutional support and non-regulatory SOPs (Government of Pakistan, 2025). Gaps in implementation capacity and the need for closer alignment between financial and sustainability outcomes are identified as barriers to green finance initiatives in Pakistan (Nasir *et al.*, 2024). While there are several studies analysing the relationship between green finance and agriculture at the macro-economic level and regional levels, primarily in China. There has been little to no evidence identifying whether green finance has an impact on the sustainability performance of agri-filled firms. Hence, there is an immediate need for firm-level literature regarding whether or not green finance impacts agri-based firm sustainability performance, resulting in enhanced resilience and greater growth opportunities.

While green finance can be a powerful tool for firm-level impact, some of the factors can mitigate its effectiveness. Firstly allocation-implementation gap, without directly financing operational and regenerative practices, firms often allocate green labelled financing to just broad environmental level commitments, ESG reporting and compliance. Secondly, there exist weak monitoring and verification procedures when it comes to the allocation of green finance practices. Sustainability outcomes can never be materialized without strong traceability and metrics of green finance. Thirdly, most of the firms in emerging markets like Pakistan lack technological capabilities to materialize financing in sustainability improvements, which makes technological adoption the binding constraint (Wang *et al.*, 2025). Lastly, institutional bottlenecks and transition costs may hinder the observable effects of green financing since Pakistan's Sustainable Framework is still in its preliminary stages of development (UNDP, 2022).

2.2 Technological Advancement and Climate Resilient Systems

Technological advancement in the agricultural sector is one of the main drivers of regenerative and climate-smart transitions. CSA framework highlights the need for technological adoption to increase agricultural productivity. Climate risk can be mitigated by enhancing water efficiency through advances in technology. Water efficiency can be easily achieved through early warning systems, optimal inputs and extension services (World Bank, 2019). Institutional and contextual factors can produce efficient adoption of Climate Smart Agriculture. However, resilient strategies for small farm holders can only be achieved through the adoption of technology (Sultan *et al.*, 2022). World Bank CSA profile highlights the institutional and policy-based challenges, which emphasizes on a strong need for enhanced technological adoption and governance to strengthen resilience. Green agriculture development can be achieved through technological innovations in the area of green technology. Many studies carried out in the agribusiness context reveal that incentives and policies for innovation can

Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

increase green technological adoption, producing favourable outcomes for environmental sustainability (Wang *et al.*, 2025).

2.3 Sustainability Performance and Firm Growth

Sustainability performance in agri-filled firms is often operationalized using a proxy of ESG performance due to its capability of reflecting environmental, social and governance practices. ESG performance has been successfully linked with ESG value creation, firm valuation, and robust firm performance in multiple studies. However, different controversies attached with ESG paradigm sometimes weaken the designated relationship (Raha *et al.*, 2024). Better resource allocation, consistent stakeholder-oriented governance, ease in financial constraints, reduced agency costs and improved investment efficiency can be produced by a firm having heightened ESG performance (Ma *et al.*, 2025). Such findings support the argument that sustainability performance can definitively inculcate better growth opportunities, long-term competitiveness and resilience specifically in the sector of agriculture. Since the agriculture sector is highly exposed to climate risk and resource scarcity.

2.4 Theoretical Framework

2.4.1 Stakeholder Theory

A firm creates value keeping in mind the needs and expectations of its stakeholders i.e., employees, suppliers, distributors, retailers, customers, regulators and investors (Harrison & Wicks, 2013). As far as small farm holders are concerned, sustainable practices can reduce conflict, support equitable food chains and strengthen the legitimacy of agri-based stakeholders who are farmers, rural labour and local eco-systems. Sustainability performance is therefore conceptualized as a stakeholder-oriented entity which can enhance growth opportunities through lowering the risk of disruption, reduced risk, enhanced resilience and trust (Raha *et al.*, 2024; Ma et al, 2025). Hence, suggesting the hypothesis:

H_1: Sustainability performance has a significantly positive impact on firm growth opportunities.

2.4.2 Resource-Based View

Competitive advantage can be achieved through rare and valuable resources like technological advances, helping firms to mitigate climate risk, produce optimal inputs, facilitate regenerative practices and measure sustainability practices. This ensures that firms having strong technological adoption tend to have more growth opportunities than the firms that do not implement technological advances (Wernerfelt, 1984; Barney, 1991). Hence, suggesting the hypothesis:

H_2: Technological advancement has a significantly positive impact on sustainability performance.

2.4.3 Finance-Innovation-Performance Mechanisms

Green finance ought to significantly facilitate sustainability. However, this is only possible if green practices are linked with innovation capacity and robust implementation. Therefore, in Pakistan, policy discussions are based upon the emphasis of implementation urgency,

IJBB
International Journal of Biotechnology and Biomedicine
Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

disclosure and targeted green finance instruments (UNDP, 2023). Hence, suggesting the following hypotheses:

H3: Green finance has a significantly positive impact on sustainability performance.
H4: Sustainability performance mediates the relationship between technological advancement and firm growth opportunities.
H5: Sustainability performance mediates the relationship between green finance and firm growth opportunities.

2.4.5 Theoretical Model

The theoretical model is illustrated in Figure 1.

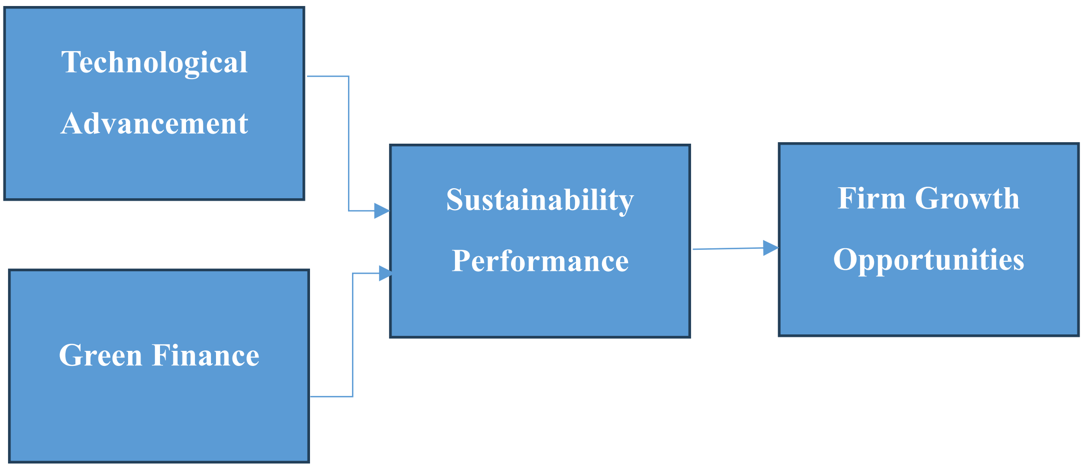

Figure 1. Theoretical Model

3.0 Research Methodology

This study has used a quantifiable explanatory research design. The aim of the study is to examine the impact of green finance and technological advances on sustainability performance and firm growth opportunities in the field of agriculture. A panel data methodology has been applied to account for both cross-sectional and time series variations. In order to estimate the proposed relationship, this study employs fixed effects panel regression in order to have reliable estimations by controlling for unobserved firm heterogeneity and time-specific effects.

3.1 Data and Sample

The dataset consists of six agri-food value firms of Pakistan listed on the Pakistan Stock Exchange, indexed in the KSE-100. These firms have been analysed from 2020 to 2024. The selection of the firms is based on the firm's agricultural input supply, sustainability metrics disclosure, food processing and logistics. These firms play a pivotal role in exerting a significant impact on regenerative outcomes and firm-level practices.
Data collection has been conducted using secondary measures. The data has been extracted mainly by performing content analysis of annual reports, the company's websites, PSX Portal, trading websites, the firm's financial statements and CSR reports. In Pakistan, the sustainability

transition can be observed in its early implementation phase. During this study period, a heightened focus on climate resilience and green finance policy in Pakistan can be rigorously observed.

3.2 Operationalization of Variables

Technological advancement and green finance are the independent variables (Table 1), Sustainability performance is the mediating variable operationalized through content analysis (Harwood & Garry, 2003; Asad *et al.*, 2025) carried out through pre-defined keywords (Appendix-A). Firm growth opportunities are taken as a dependent variable and are operationalized as market to book ratio.

Table 1
Independent variables: Technological advancement and green finance

Variable	Measure	Operationalization
Technological Advancement (ATA)	ATA-it = $\frac{\sum_{J=1}^{n} T\_ijt}{n}$	Where: ATAit = Agricultural technological advancement score for firm *i* in year *t*. Tijt = Presence of technological factor *j* in firm *i* during year *t* (1 = present, 0 = absent). n = Total number of technological advancement indicators.
Green Finance (GF)	GF-it = $\frac{\sum_{J=1}^{n} G\_ijt}{n}$	Where: GFit= Green finance score for firm *i* in year *t*. Gijt = Presence of green finance indicator *j* for firm *i* in year *t* (1 = present, 0 = absent). n = Total number of green finance indicators.
Sustainability Performance (SAP)	ESG-Score	Calculated through ESG-Score Index (Asad *et al.*, 2025)
Firm Growth Opportunities (AGFO)	AFGO-it = $\frac{Market\ Value\ Per\ Share\_it}{Book\ Value\ Per\ Share\_it}$	Where: AFGOit= Market-based firm growth opportunity indicator for firm *i* in year *t*.

3.3 Econometric Specification

To estimate the proposed relationship following models (Fixed-effects panel regression) will be employed:

Model 1(Sustainability Model)

$$SAP_{it} = \propto + \beta_1 GF_{it} + \beta_2 ATA_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Model 2 (Growth Opportunity Model)

$$AFGO_{it} = \propto + \gamma_1 SAP_{it} + \mu_i + \varepsilon_{it}$$

Model 3 (Mediation Analysis)

$$AFGO_{it} = \propto + \delta_1 GF_{it} + \delta_2 ATA_{it} + \delta_3 SAP_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

Where;
i = Firm
t = Year
μ_i = Unobserved Firm-specific Effects
λ_t = Time-specific Effects
ε_{it} = Error Term

3.4 Estimation Technique

The data analysis has been conducted through Jupyter Notebook using Python. The study incorporates fixed effects panel regression in order to control for unobserved characteristics like organizational culture, sectoral dynamics, leadership, managerial capability etc. Before applying panel. This approach is most suitable for enhancing the credibility of causal inference and minimizing omitted variable bias. Cluster robust standard errors are being used to account for firm-level serial correlation and heteroskedasticity.

While conducting panel regression, the WG-Bootstrap technique has been applied due to limitations of tech advances and the sustainable framework being introduced in the Pakistani agri-business sector barely five years ago. So, in order to have robust and reliable results, a bootstrap technique followed by 5000 replications has been applied (Asad *et al.*, 2025). If the estimation techniques are chosen wisely and interpretations are carried out cautiously, panel regression can be used for small samples (Santos & Barios, 2011; Abonazel, 2016). The study has employed F-Test poolability, R-Square and Robust F-Statistic, sensitivity analysis, and WG-Bootstrap in order to account for robustness.

4.0 Results

According to Model 1 ATA → SAP is statistically positively significant (β = 0.0850, P = 0.0013). GF → SAP is statistically insignificant (β = 0.00003, P = 0.996) [Table 2]. This proves that green finance does not lead to any statistically significant improvement in the sustainability outcomes.

Table 2
Model 1 GF and ATA as drivers of SAP

Variable	Coef.	Std. Err.	t-stat	p-value	95% CI
Constant	1.0416	0.0269	38.730	0.0000***	[0.9851, 1.0981]
GF	0.0000326	0.0631	0.0005	0.9996	[-0.1326, 0.1327]
ATA	0.0850	0.0223	3.8045	0.0013***	[0.0381, 0.1319]

Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

A robust F-P value suggests GF and ATA jointly and significantly explain SAP after applying fixed effects and clusters. The significance of the P value for poolability explains why to reject poolability. R-squared explains that Gf and ATA explain 30% of the variations in SAP (Table 3).

Table 3
Model Statistics

Statistic	Value
R^2 (Overall)	0.3046
R^2 (Between)	0.3021
F-statistic (standard) p-value	0.2579
F-statistic (robust)	7.6932
Robust F p-value	0.0038***
F-test for Poolability	4.8430 (p = 0.0022***)
Effects included	Firm FE + Year FE

According to model 2, SAP→AFGO is positively significant ($\lambda = 2.3503$, P = 0.0316) [Table 4]. This demonstrates that firms exhibiting a higher sustainability performance level tend to have more growth opportunities.

Table 4
Model 2 SAP as a predictor of AFGO

Variable	Coef.	Std. Err.	t-stat	p-value	95% CI
Constant	-1.3558	1.1031	-1.2291	0.2341	[-3.6646, 0.9530]
SAP	2.3503	1.0129	2.3202	0.0316**	[0.2301, 4.4704]

A robust F-P value suggests SAP significantly explains AFGO after applying fixed effects and clusters. The significance of the P value for poolability explains why to reject poolability. R-squared explains that SAP explain 4% of the variations in AFGO (Table 5). Still holding a significant relationship.

Table 5
Statistics

Statistic	Value
R^2 (Overall)	0.0451
R^2 (Between)	0.0437
R^2 (Within)	0.0489
F-statistic (standard) p-value	0.4697
F-statistic (robust)	5.3834

Statistic	Value
Robust F p-value	0.0316**
F-test for Poolability	6.9133 (p = 0.0002***)
Effects included	Firm FE + Year FE

The third model accounts for the mediation results GF, ATA, SAP → AFGO. SAP remains statistically positively significant ($\delta = 4.730$, P = 0.0064). GF remains insignificant (p= 0.8959). However, ATA becomes significant ($\delta = -1.4176$, p= 0.0613) [Tables 6 & 7]. This exhibits a classic case of full mediation. This indicates that any technological change that does not translate into sustainability performance does not increase firm growth. Technology is only valuable when it is used for sustainability; technological advances not translate into regenerative outcomes are economically unproductive.

Table 6
Model 3 Full Mediation Model

Variable	Coef.	Std. Err.	t-stat	p-value	95% CI
Constant	-3.1359	1.5363	-2.0412	0.0571*	[-6.3773, 0.1054]
GF	-0.1063	0.8009	-0.1328	0.8959	[-1.7960, 1.5833]
ATA	-1.4176	0.7076	-2.0035	0.0613*	[-2.9104, 0.0752]
SAP	4.7430	1.5254	3.1093	0.0064***	[1.5246, 7.9614]

Table 7
Mediation Indirect Effects

Indirect Path	Indirect Effect
GF → SAP → AFGO	0.000077
ATA → SAP → AFGO	0.199784

The indirect effect further validates the mediation. This confirms that firm growth opportunities are increased by technological advancement when carried through sustainability performance. However, green finance does not exhibit a comparable effect.

5.0 Discussion

The statistically strong relationship between technological advancement and sustainability performance reveals that technology indeed is a very powerful enabler of sustainability. Reduced waste, lower emissions intensity, improved water stewardship can be successfully achieved through technological adoption such as supply chain traceability, precision input management, digital advisory services and improved irrigation systems (World Bank). These findings are in line with the CSA framework, exhibiting that technology plays a central role in adaptation and resilience. These results are also supported by the research conducted by Wang *et al.* (2025), suggesting that green technology innovation in agri-based firms is certainly a pathway towards green agricultural development. The negative sign with the ATA coefficient (Table 6) does not contradict the positive role played by the technology in order to achieve

Sustainable Development Goals (SDGs). Instead, the negative sign is an indication of a suppression effect, implying that technological advancement can only be helpful for firm growth if it's translated through sustainability.

Green finance has depicted an insignificance that remained persistent in model 3. These results are extremely important as it showcases that emerging economies may emphasize a lot on green financing yet green finance practices in economies like Pakistan are not translated into effective sustainability measures at firm-level, most likely due to lack of technical absorptive capacity, targeting gaps, lack of implementation, insufficient monitoring, insufficient project readiness, limited verification protocols and lack of infrastructure supporting green financing (Chu *et al.*, 2024; Mo *et al.*, 2023; Lee *et al.*, 2022).

In order to ensure fairness for small farm holders and marginalized communities, technological advancement in agriculture is most relevant for equity. Our firm-level pathway identifies that technological adaptation improves sustainability performance, which is a subset of governance compliance and social inclusion. The higher the sustainability performance more the supplier engagement, inclusive procurement and stronger value chain upgrading can be achieved through resilient and investable conditions created by sustainability-oriented firms. Agri-business can inculcate reduced financing constraints, improved investment efficiency through ESG-aligned practices and stakeholder-oriented value creation (Ma *et al.*, 2025).

While improving livelihoods, regenerative agriculture has a strong emphasis on soil organic matter, water cycling, restoring ecosystems, and biodiversity. This study employs firm-level sustainability performance (based on ESG proxy), ensuring elements like water stewardship, governance compliance, water-efficient irrigation, environmental sustainability, biodiversity friendly sourcing are captured. However, green finance will only matter if monitored through measurable practices (Table 8). This urges a strong need for implementation channels to reinforce green financial practices (UNDP, 2022).

Table 8
Hypotheses Decision Summary

Hypothesis	Path	Supported?	Evidence
H1	SAP → AFGO	**Supported**	Model 2 p = 0.0316; Model 3 p = 0.0064
H2	ATA → SAP	**Supported**	Model 1 p = 0.0013
H3	GF → SAP	**Not supported**	Model 1 p = 0.9996
H4	ATA → SAP → AFGO	**Supported**	[0.002577, 0.523377]
H5	GF → SAP → AFGO	**Not supported**	[-0.393752, 0.534057]

Conclusion

This study examined the impact of green finance and technology advancement on sustainability performance and whether sustainability performance mediates firm growth in Pakistan's agri-filled sector (2020-2024). The study employed firm and year fixed effects panel regression, accompanied by clustered standard errors, WG Bootstrap and mediation analysis. The results indicate that technological advancement significantly improves sustainability performance. Sustainability performance significantly impacts firm growth opportunities. The findings also indicate that the sustainability performance mediates the relationship between firm growth opportunities and technological advancement. This indicates the technology only supports firm growth when translated into sustainability performance. Green finance has no impact on sustainability performance, emphasizing the need of implementing monitoring for finance-implementation channels. Overall evidence indicates that climate-resilience and regenerative transition at the firm level can be driven through technology. However, in order to ensure measurable sustainability performance through green finance, it must be designed better in linked with implementation.

Implication

Technology diffusion policies like irrigation modernization, water stewardship technologies and digital extension must be prioritized by the government and regulators. In order to strengthen green finance, the government should ensure measurable KPIs, monitoring and taxonomies translating funds into on-ground outcomes. Verifiable sustainability metrics and technology usage must be tied together through green lending by financial institutions. Blended finance and technical assistance used to reduce the finance-implementation gap must be supported by donors and development partners.

References

Abonazel, M. R. (2016). Generalized random coefficient estimators of panel data models: Asymptotic and small sample properties. *Journal of Statistical Theory and Applications, 15*(1), 1–18.

Asad, S., Bhaumik, A., & Khan, M. K. (2025). The Tech Prescription: Innovating Sustainable Health. *International Journal of Biotechnology and Biomedicine (IJBB)*, *1*(4), 43-61.

Asad, S., & Amiya Bhaumik. (2025). Crafting Pakistan's ESG Performance Blueprint: A Framework for Sustainable Growth. *International Journal of Computational and Experimental Science and Engineering*, *11*(3). 5257-5270

Asad, S., & Amiya Bhaumik. (2025). Nexus of Artificial Intelligence, Green Finance and The Banking Industry of Pakistan. *International Journal of Computational and Experimental Science and Engineering*, *11*(3). 5317-5327.

Chu, L., Zhang, X., & Liu, J. (2024). Influence of green finance on agricultural green total factor productivity: Evidence from China. *Frontiers in Environmental Science, 12*, 1463833.

Government of Pakistan, Ministry of Climate Change. (2025). *Draft Pakistan green taxonomy*. Government of Pakistan.

Harwood, T. G., & Garry, T. (2003). An overview of content analysis. *The Marketing Review, 3*(4), 479–498.

Lee, C.-C., Lee, C.-C., & Ning, S.-L. (2022). How does green finance affect green total factor productivity? Evidence from China. *Energy Economics, 107*, 105863.

Ma, A., Li, Y., & Zhou, H. (2025). The impact of ESG performance on corporate investment efficiency: Evidence from Chinese agribusiness companies. *Sustainability, 17*(16), 7362.

Mo, Y., Sun, D., & Zhang, Y. (2023). Green finance assists agricultural sustainable development: Evidence from China. *Sustainability, 15*(3), 2056.

Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

Nasir, N., Iqbal, J., & Khan, A. (2024). Emerging pathways of green financing and its role in inducing sustainable development in Pakistan. *Journal of Accounting and Finance Review, 10*(2), 45–62.

Rahat, B., & Nguyen, D. K. (2024). The impact of ESG profile on firm's valuation in emerging markets. *Finance Research Letters, 95*, 105752.

Santos, L. A., & Barrios, E. B. (2011). Small sample estimation in dynamic panel data models: A simulation study. *Open Journal of Statistics, 1*(2), 58–73.

Sultan, M. S., Khan, M. A., Khan, H., & Ahmad, B. (2022). Pathways to strengthening capabilities: A case for the adoption of climate-smart agriculture in Pakistan. *APN Science Bulletin, 12*(1), 171–183.

UNDP. (2023). *Policy brief: Greening the financial system of Pakistan*. United Nations Development Programme.

Wang, W., Ahmad, M., & Kumar, R. (2025). Unleashing green technology innovation in agribusiness: Implications for sustainable development. *Humanities and Social Sciences Communications*.

World Bank. (2019). *Climate-smart agriculture in Pakistan*. World Bank Climate Knowledge Portal.

Appendix A

Keywords for Technological Advancement

Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

Category	**Keywords / Indicators**
Digital & Smart Farming Technologies	precision agriculture, digital farming, smart farming, digital agriculture, farm management software, decision support systems, cloud-based farm systems, agricultural apps, e-extension services
Artificial Intelligence & Data Analytics	artificial intelligence in agriculture, AI-based crop monitoring, machine learning in farming, predictive analytics, yield prediction algorithms, crop disease detection AI
Remote Sensing & GIS	satellite imagery, drone monitoring, UAV agriculture, GIS mapping, geospatial analysis, NDVI monitoring, spatial crop analysis
Internet of Things (IoT)	IoT-based irrigation, smart sensors, soil moisture sensors, climate sensors, automated field monitoring, sensor-based agriculture
Water Management & Irrigation Technologies	drip irrigation systems, smart irrigation, automated irrigation scheduling, water-efficient irrigation, precision water management
Soil Health & Input Optimization	soil nutrient sensors, precision fertilization, variable rate technology, nutrient management systems, site-specific soil management
Climate-Smart Agriculture Technologies	climate-smart agriculture, drought-tolerant technologies, heat-resilient crop systems, climate risk modelling, adaptation technologies
Mechanization & Automation	autonomous tractors, robotics in farming, automated harvesters, smart machinery, robotic crop monitoring
Biotechnology & Seed Innovation	high-yield seed varieties, genetically improved crops, pest-resistant seeds, stress-tolerant crops, hybrid seed technology
Supply Chain & Traceability Technologies	blockchain traceability, digital supply chain systems, QR-code tracking, farm-to-fork traceability platforms
Energy & Low-Carbon Technologies	solar-powered irrigation, renewable energy in agriculture, low-emission machinery, bio-energy systems
Farm Financial & Advisory Technologies	agri-fintech platforms, digital credit scoring, mobile advisory services, farmer digital finance tools
Post-Harvest & Storage Innovations	smart cold storage, IoT-enabled warehouses, post-harvest loss monitoring, digital inventory systems

IJBB
International Journal of Biotechnology and Biomedicine
Vol. 2 No4; February 2026 https://doi.org/10.31674/ijbb.2025.v02i04.005

Keywords for Green Finance

Category	Keywords
Green Finance	green finance, green financial instruments, green bonds, green sukuk, green loan, green credit, green funding, green refinancing, green investment, green project finance, green capital, green lending, green portfolio, green economy, green infrastructure.
Climate and Carbon Emissions	climate finance, carbon finance, carbon credits, carbon trading, carbon offset, carbon reduction, carbon footprint, emission trading, low carbon, carbon neutrality, net zero, decarbonization.
Renewable Energy and Sustainable Projects	renewable energy, renewable energy finance, sustainable finance, sustainability-linked finance, clean energy, solar energy, hydropower, wind energy, bioenergy, energy efficiency, eco investment, pollution control, waste management, water conservation, environmental finance, "environmental sustainability project.
SBP/ State Bank of Pakistan Schemes	SBP green finance, SBP refinance scheme, SBP renewable energy, SBP energy efficiency, state bank green financing.
Institutional and Funds	green fund, climate fund, carbon fund, clean technology fund, renewable fund, environmental fund, energy transition fund.
Policy and Reporting	green policy, green credit policy, green financing framework, green disclosure, ESG finance, sustainability reporting, sustainable project financing, sustainable development goals, SDG financing, green initiative, green program, green strategy
Related Terms	green mortgage, green insurance, green banking, green microfinance, eco-friendly investment, eco-friendly banking, climate adaptation, climate mitigation, environmental protection financing, circular economy, environmental development fund, energy transition