



An Empirical Analysis of Sustainable Agricultural Finance Adoption among South Indian Farmers

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Abstract

Sustainable agricultural finance has become an important mechanism for promoting climate-resilient agriculture and supporting the long-term sustainability of farming systems. Despite its growing importance, the adoption of sustainable financial products among farmers remains uneven, particularly in developing regions where institutional, technological and financial constraints continue to shape investment decisions. This study examines the determinants of sustainable agricultural finance adoption among farmers in Kerala, Karnataka and Tamil Nadu by analysing the influence of financial literacy, climate risk awareness, digital readiness and institutional support. A quantitative cross-sectional survey was conducted among 438 farmers using a structured questionnaire. The collected data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM). The findings show that all four determinants significantly influence sustainable agricultural finance adoption. Institutional support emerged as the strongest predictor ($\beta = 0.312$), followed by digital readiness ($\beta = 0.241$), financial literacy ($\beta = 0.218$) and climate risk awareness ($\beta = 0.186$). The proposed model demonstrated satisfactory explanatory power ($R^2 = 0.524$), strong predictive relevance ($Q^2 = 0.391$) and good model fit (SRMR = 0.067; NFI = 0.914). The findings indicate that strengthening institutional mechanisms, expanding digital financial infrastructure, improving financial literacy and increasing climate risk awareness are essential for encouraging sustainable agricultural finance adoption. The study adds to the growing literature on sustainable agricultural finance by providing empirical evidence from South India and offers practical guidance for policymakers, financial institutions and agricultural development agencies seeking to strengthen sustainable financial systems and promote resilient agricultural development.

Keywords: Sustainable Agricultural Finance, Financial Literacy, Climate Risk Awareness, Digital Readiness, Institutional Support

1. INTRODUCTION

Agriculture remains a fundamental pillar of economic development, making a significant contribution to food security, employment generation and rural livelihoods across developing economies [1-2]. The agricultural sector in India supports nearly half of the workforce and provides the foundation for national food production and rural income generation. The sector, however, continues to face persistent structural challenges, including fragmented landholdings, declining natural resources, production uncertainties, market volatility and limited access to institutional finance. These constraints have become more pronounced under changing climatic conditions, where rising temperatures, irregular rainfall patterns, prolonged droughts and frequent floods threaten agricultural productivity and the long-term sustainability of farming systems [3]. Addressing these challenges requires not only technological innovation but also financial mechanisms that enable farmers to invest in climate-resilient and environmentally sustainable agricultural practices.

Sustainable agricultural finance has emerged as an important instrument for supporting the transition towards resilient agricultural production systems [3,6]. Unlike conventional agricultural credit, sustainable agricultural finance encourages investments that promote economic viability, environmental protection and social sustainability at the same time. Financial instruments such as concessional green credit, climate-linked loans, weather-indexed insurance, blended finance and sustainability-oriented lending programmes encourage farmers to adopt resource-efficient technologies, strengthen farm resilience and reduce exposure to climate-related risks [4-5]. Governments, financial institutions and international development agencies have expanded



sustainable finance initiatives in recent years to support climate-smart agriculture and strengthen agricultural sustainability. Their success, however, depends largely on farmers' willingness and capacity to adopt sustainable financial products and services [3,5].

Although the institutional framework supporting sustainable agricultural finance has expanded considerably, adoption among farmers remains uneven. While some farmers actively use sustainable financial services to modernise their farming operations, many continue to rely on conventional credit systems or informal borrowing arrangements. Variations in financial capability, awareness of climate-related risks, digital preparedness and access to institutional support often shape farmers' decisions regarding the adoption of sustainable agricultural finance [8-9]. Increasing the availability of financial products alone may therefore be insufficient unless individual capabilities and institutional conditions are strengthened alongside them. Understanding these behavioural and structural factors has become an important priority for policymakers seeking to improve the effectiveness of sustainable agricultural finance programmes [7].

Previous studies have examined agricultural finance, financial inclusion, climate adaptation, digital financial services and agricultural technology adoption from different theoretical perspectives [3, 10, 7]. Existing evidence consistently shows that financial literacy improves financial decision-making, climate risk awareness encourages adaptive behaviour, digital readiness enhances access to financial services and institutional support promotes agricultural innovation and technology adoption [8, 10, 2]. Much of the available literature, however, has examined these factors independently or has focused mainly on agricultural technology adoption rather than sustainable agricultural finance adoption as a distinct behavioural outcome [3]. Previous research has also relied largely on conventional statistical techniques that estimate the independent influence of explanatory variables while offering limited understanding of how different combinations of individual and institutional factors shape farmers' adoption decisions. Empirical evidence from South India remains relatively limited despite the region's diversity in agricultural production systems, financial infrastructure and digital transformation.

Against this background, the present study investigates the determinants of sustainable agricultural finance adoption among farmers in South India by examining the influence of financial literacy, climate risk awareness, digital readiness and institutional support. The study provides empirical evidence from farmers in Kerala, Karnataka and Tamil Nadu, representing diverse agricultural and institutional environments. To achieve a broader understanding of adoption behaviour, the study combines Partial Least Squares Structural Equation Modelling (PLS-SEM) with fuzzy-set Qualitative Comparative Analysis (fsQCA). PLS-SEM identifies the relative influence of individual determinants, whereas fsQCA examines alternative combinations of conditions associated with high levels of sustainable agricultural finance adoption, providing complementary evidence on both symmetric and asymmetric relationships [11-13]. The findings add to the growing body of knowledge on sustainable agricultural finance by extending current understanding of farmers' adoption behaviour through an integrated analytical framework. The study also provides practical evidence for governments, financial institutions, agricultural extension agencies and development organisations seeking to strengthen sustainable finance policies, improve financial inclusion and accelerate the adoption of climate-resilient agricultural practices [14-15].

The findings add to the growing body of knowledge on sustainable agricultural finance by extending current understanding of farmers' adoption behaviour through an integrated analytical framework. The study also provides practical evidence for governments, financial institutions, agricultural extension agencies and development organisations seeking to strengthen sustainable finance policies, improve financial inclusion and accelerate the adoption of climate-resilient agricultural practices [16]. By identifying the key drivers of sustainable agricultural finance adoption, the study offers practical guidance for designing targeted interventions that promote sustainable agricultural development and strengthen farmers' resilience to emerging environmental and economic challenges [17].

2. RESEARCH METHOD

2.1 Research Design and Sampling

This study adopted a quantitative research approach using a cross-sectional survey design to examine the determinants of sustainable agricultural finance adoption among farmers in South India. The study was carried out across the states of Kerala, Karnataka and Tamil Nadu, selected because of their agricultural importance, climatic vulnerability and differences in financial inclusion, digital infrastructure and institutional support. The target population comprised land-owning and tenant farmers actively engaged in crop cultivation.



A multi-stage stratified random sampling technique was employed to obtain a representative sample. Initially, the three states were purposively selected, followed by the selection of major agricultural districts representing diverse cropping systems and climatic conditions. Villages were then selected using probability proportional to size sampling, and respondents were randomly chosen from land revenue records, Kisan Credit Card databases and cooperative membership lists. Farmers with a minimum of two years of farming experience were included in the study, while livestock-only enterprises, corporate farms and absentee landowners were excluded. A total of 450 questionnaires were administered, of which 438 valid responses were retained after data screening, resulting in an effective response rate of 97.3 per cent.

2.2 Data Collection and Measurement

Primary data were collected through structured face-to-face interviews using a questionnaire developed from validated measurement scales reported in earlier studies. The questionnaire comprised five latent constructs: Financial Literacy, Climate Risk Awareness, Digital Readiness, Institutional Support and Sustainable Agricultural Finance Adoption. All items were measured using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The questionnaire was reviewed by experts in agricultural finance, climate adaptation and rural development to ensure content validity and contextual relevance. A pilot survey was subsequently conducted among farmers outside the study area, and the feedback received was incorporated before administering the final questionnaire.

2.3 Data Analysis

The collected data were screened for missing values, outliers and inconsistencies before statistical analysis. Descriptive statistics were used to summarise the demographic characteristics of the respondents and examine the distribution of the study variables. Partial Least Squares Structural Equation Modelling (PLS-SEM) was employed to examine the hypothesised relationships between Financial Literacy, Climate Risk Awareness, Digital Readiness, Institutional Support and Sustainable Agricultural Finance Adoption. Before evaluating the structural model, the measurement model was assessed to confirm the reliability and validity of the study constructs. The structural relationships were then evaluated using bootstrapping procedures, path coefficients, effect sizes (f^2), coefficients of determination (R^2), predictive relevance (Q^2) and model fit indices, including the Standardised Root Mean Square Residual (SRMR) and the Normed Fit Index (NFI). These analytical procedures provided a sound basis for evaluating the determinants of sustainable agricultural finance adoption among farmers in South India.

3. ANALYSIS AND DISCUSSION

Table 1 Demographic Profile of Respondents (N = 438)

Characteristic	Category	Frequency (n)	Percentage (%)
State	Kerala	146	33.3
	Karnataka	147	33.6
	Tamil Nadu	145	33.1
Gender	Male	362	82.6
	Female	76	17.4
Age Group	< 30 years	45	10.3
	30–40 years	128	29.2
	41–50 years	156	35.6
	> 50 years	109	24.9
Education Level	No formal education	52	11.9
	Primary (1–5 years)	98	22.4
	Secondary (6–10 years)	156	35.6
	Higher secondary (11–12 years)	87	19.9
	Graduate & above	45	10.3



Farm Size	Small (< 2 ha)	221	50.5
	Medium (2–5 ha)	131	29.9
	Large (> 5 ha)	86	19.6
Major Crop Cultivated	Paddy	105	24
	Vegetables	88	20.1
	Plantation crops	94	21.5
	Millets/Pulses	63	14.4
	Horticulture	55	12.6
	Mixed farming	33	7.5
Farming Experience	< 10 years	89	20.3
	10–20 years	167	38.1
	> 20 years	182	41.6
Annual Agricultural Income	< ₹2 lakhs	156	35.6
	₹2–5 lakhs	187	42.7
	> ₹5 lakhs	95	21.7
Land Ownership	Own land	289	66
	Leased land	67	15.3
	Both	82	18.7
Irrigation Access	Yes	312	71.2
	No	126	28.8
Farmer Organisation Membership	Member	198	45.2
	Non-member	240	54.8
Access to Financial Services	Bank account only	142	32.4
	Bank + credit access	178	40.6
	Informal finance only	88	20.1
	No financial access	30	6.9
Digital Device Ownership	Smartphone	334	76.3
	Feature phone	79	18
	Computer/Laptop	25	5.7
	No device	7	1.6

Source: Primary Data

The demographic and socio-economic characteristics of the 438 farmers surveyed across Kerala, Karnataka and Tamil Nadu are summarised in Table 1. The respondents were almost equally distributed across the three states, ensuring balanced representation of the major agricultural regions of South India. This balanced distribution reduces regional bias and strengthens the applicability of the findings across diverse agro-climatic, institutional and financial settings. The selected states differ considerably in cropping patterns, climate variability and financial infrastructure, providing an appropriate setting for examining the determinants of sustainable agricultural finance adoption. The sample was predominantly male (82.6%), reflecting the continued dominance of men in farm ownership, production management and financial decision-making within the agricultural sector. At the same time, the inclusion of female respondents captures the growing participation of women in agricultural activities and draws attention to the need for inclusive financial policies that address gender disparities in access to sustainable agricultural finance. The age profile indicates that most respondents belonged to the economically productive age groups, particularly those aged 41–50 years (35.6%), while nearly four-fifths possessed more than ten years of farming experience. This demographic profile suggests that the respondents had accumulated substantial practical knowledge of agricultural production, financial management and climate-related challenges, enabling them to provide informed responses on sustainable financial practices. Educational attainment was



relatively encouraging, with most respondents having completed at least secondary education. This level of education is likely to enhance farmers' ability to understand financial products, adopt digital financial services and make effective use of institutional support programmes. More than half of the respondents operated small farms, reflecting the fragmented landholding pattern that characterises agriculture in Kerala, Karnataka and Tamil Nadu. Smallholder farmers generally face greater financial constraints and investment risks, making access to sustainable agricultural finance particularly important for improving farm productivity and resilience. The distribution of annual agricultural income also shows that a substantial proportion of farmers belonged to low and middle-income groups, highlighting the importance of affordable and accessible financial services. Although most respondents cultivated their own land and had access to irrigation facilities, membership in farmer organisations remained moderate, indicating scope to strengthen collective institutional support and agricultural extension services. The high level of smartphone ownership, together with comparatively lower access to computers, also reflects the growing potential of mobile-based financial technologies to expand sustainable agricultural finance across the study area. The demographic and socio-economic profile therefore provides a sound foundation for examining the factors influencing sustainable agricultural finance adoption among farmers in South India.

Table 2 Descriptive Statistics and Correlation Matrix (N = 438)

Variable	Mean	SD	1	2	3	4	5
1. Financial Literacy (FL)	3.12	0.84	1				
2. Climate Risk Awareness (CRA)	3.67	0.76	0.42*	1			
3. Digital Readiness (DR)	2.89	0.91	0.51*	0.38*	1		
4. Institutional Support (IS)	2.74	0.82	0.46*	0.44*	0.49*	1	
5. Sustainable Agricultural Finance Adoption (SAFA)	2.96	0.88	0.58*	0.52*	0.56*	0.61*	1

Source: Computed from Primary Data

Note: ** indicates significance at the 0.01 level (two-tailed). Higher scores indicate stronger perceptions or higher levels of sustainable agricultural finance adoption.

The descriptive statistics and correlation matrix for the study variables are reported in Table 2. The mean scores indicate moderate levels of Financial Literacy (Mean = 3.12, SD = 0.84), Digital Readiness (Mean = 2.89, SD = 0.91), Institutional Support (Mean = 2.74, SD = 0.82) and Sustainable Agricultural Finance Adoption (Mean = 2.96, SD = 0.88). Climate Risk Awareness, however, recorded the highest mean score (Mean = 3.67, SD = 0.76), suggesting that farmers across Kerala, Karnataka and Tamil Nadu have a relatively high level of awareness of climate-related challenges affecting agricultural production. The comparatively lower mean scores for Digital Readiness and Institutional Support point to areas that require greater policy attention to improve farmers' access to sustainable financial services. The standard deviation values ranged from 0.76 to 0.91, indicating moderate variation in respondents' perceptions without substantial dispersion. This pattern reflects a reasonable level of consistency in responses while capturing the socio-economic and institutional diversity of the study area. The correlation analysis showed positive and statistically significant relationships among all study variables at the 0.01 significance level. Financial Literacy exhibited moderate positive associations with Climate Risk Awareness ($r = 0.42$), Digital Readiness ($r = 0.51$), Institutional Support ($r = 0.46$) and Sustainable Agricultural Finance Adoption ($r = 0.58$). Climate Risk Awareness also showed positive relationships with Digital Readiness ($r = 0.38$), Institutional Support ($r = 0.44$) and Sustainable Agricultural Finance Adoption ($r = 0.52$). Digital Readiness demonstrated significant positive relationships with Institutional Support ($r = 0.49$) and Sustainable Agricultural Finance Adoption ($r = 0.56$). Institutional Support recorded the strongest correlation with Sustainable Agricultural Finance Adoption ($r = 0.61$), reflecting its important role in encouraging farmers' participation in sustainable financial programmes. All correlation coefficients remained below the commonly accepted threshold of 0.80, indicating the absence of serious multicollinearity among the explanatory variables. These relationships provide initial empirical support for the proposed conceptual framework and justify the subsequent structural model analysis examining the direct effects of Financial Literacy, Climate Risk Awareness,



Digital Readiness and Institutional Support on Sustainable Agricultural Finance Adoption among farmers in South India.

Table 3 Structural Model Assessment and Hypothesis Testing

Hypotheses	Path	β	SE	t-value	p-value	95% CI	Decision	f ²	Effect Size
H1	Financial Literacy → SAFA	0.218	0.052	4.192	<0.001	[0.116, 0.320]	Supported	0.068	Small
H2	Climate Risk Awareness → SAFA	0.186	0.048	3.875	<0.001	[0.092, 0.280]	Supported	0.052	Small
H3	Digital Readiness → SAFA	0.241	0.054	4.463	<0.001	[0.135, 0.347]	Supported	0.082	Small to Medium
H4	Institutional Support → SAFA	0.312	0.056	5.571	<0.001	[0.202, 0.422]	Supported	0.145	Medium

Source: Computed from Primary Data

Note: Bootstrap samples = 5,000; β = standardized path coefficient; SE = standard error; CI = bias-corrected 95% confidence interval.

The structural model assessment obtained through Partial Least Squares Structural Equation Modelling (PLS-SEM) is reported in Table 3. The bootstrapping analysis based on 5,000 resamples confirmed that all four hypothesised relationships were positive and statistically significant, providing empirical support for the proposed research framework. The absence of zero within the 95% bias-corrected confidence intervals further confirms the robustness and stability of the estimated path coefficients. Institutional Support exerted the strongest influence on Sustainable Agricultural Finance Adoption ($\beta = 0.312$, $t = 5.571$, $p < 0.001$), indicating that government initiatives, financial institutions and agricultural extension services play a critical role in encouraging farmers to adopt sustainable financial products and practices. This result highlights the importance of strengthening institutional mechanisms to improve farmers' access to credit, advisory services and financial incentives across Kerala, Karnataka and Tamil Nadu. The corresponding effect size ($f^2 = 0.145$) indicates a moderate practical contribution, identifying Institutional Support as the most influential determinant in the proposed model. Digital Readiness emerged as the second strongest predictor ($\beta = 0.241$, $t = 4.463$, $p < 0.001$), with a small-to-medium effect size ($f^2 = 0.082$). This reflects the growing importance of digital technologies in improving access to financial information, digital banking services and technology-enabled agricultural support systems. As smartphone penetration continues to increase across the study area, strengthening farmers' digital capability is likely to improve participation in sustainable agricultural finance programmes. Financial Literacy also demonstrated a significant positive influence on Sustainable Agricultural Finance Adoption ($\beta = 0.218$, $t = 4.192$, $p < 0.001$), confirming that farmers with stronger financial knowledge are better able to evaluate financial products, make informed investment decisions and utilise sustainable financing opportunities. Climate Risk Awareness likewise showed a positive and statistically significant relationship with adoption ($\beta = 0.186$, $t = 3.875$, $p < 0.001$), indicating that greater awareness of climate-related risks encourages farmers to seek financial instruments that strengthen farm resilience. Although both variables recorded relatively small effect sizes, their statistically significant contributions confirm that behavioural and cognitive factors remain important components of sustainable agricultural finance adoption. The findings confirm that Financial Literacy, Climate Risk Awareness, Digital Readiness and Institutional Support each have a positive influence on Sustainable Agricultural Finance Adoption among farmers in South India. The stronger influence of Institutional Support and Digital Readiness also indicates that strengthening institutional frameworks and expanding digital financial ecosystems should remain central priorities for promoting sustainable agricultural development and improving farmers' financial resilience.

Table 4 Model Fit and Predictive Assessment

Indicator	Value	Interpretation
R ² (SAFA)	0.524	Moderate explanatory power



Adjusted R ²	0.519	Adjusted explanatory power
Q ²	0.391	Strong predictive relevance
SRMR	0.067	Good model fit (< 0.08)
NFI	0.914	Acceptable model fit (> 0.90)

Source: Computed from Primary Data

The model fit and predictive assessment of the proposed structural model are reported in Table 4. The coefficient of determination ($R^2 = 0.524$) indicates that Financial Literacy, Climate Risk Awareness, Digital Readiness and Institutional Support jointly explain 52.4% of the variation in Sustainable Agricultural Finance Adoption among farmers in Kerala, Karnataka and Tamil Nadu. This level of explanatory power shows that the proposed model captures the major determinants influencing farmers' adoption behaviour, while recognising that other contextual factors may also affect adoption decisions. The adjusted coefficient of determination (Adjusted $R^2 = 0.519$) remains very close to the original R^2 value, confirming the stability of the model after accounting for the number of explanatory variables. The small difference between these two statistics indicates that the model is not overfitted and retains satisfactory explanatory capability. The predictive relevance statistic ($Q^2 = 0.391$) also exceeds the recommended threshold of zero, confirming that the model possesses strong predictive capability for Sustainable Agricultural Finance Adoption. The overall model fit was found to be satisfactory. The Standardised Root Mean Square Residual (SRMR = 0.067) is below the recommended threshold of 0.08, indicating a good fit between the proposed model and the observed data. Likewise, the Normed Fit Index (NFI = 0.914) exceeds the recommended benchmark of 0.90, providing further evidence of the adequacy of the structural model. The results confirm that the proposed model provides a reliable and statistically sound framework for explaining Sustainable Agricultural Finance Adoption among farmers in South India. The satisfactory explanatory power, predictive relevance and model fit strengthen the validity of the structural relationships identified in the previous section and support the use of the model for developing practical implications and policy recommendations.

4. IMPLEMENTATION

The empirical findings provide useful guidance for designing interventions that encourage sustainable agricultural finance adoption among farmers in South India. As Institutional Support emerged as the strongest determinant, strengthening institutional mechanisms should be the primary implementation priority. Government agencies, agricultural departments, commercial banks, cooperative institutions and extension services should work together to develop integrated financial support systems that improve farmers' access to sustainable credit, insurance products and investment incentives. Simplifying loan procedures, expanding outreach through local financial institutions and strengthening advisory services can increase farmers' confidence in adopting sustainable financial instruments.

Digital Readiness emerged as the second most influential determinant, reflecting the growing importance of digital technologies in agricultural finance. Financial institutions should expand digital banking infrastructure and promote mobile-based financial services tailored to the needs of farming communities. User-friendly applications providing information on sustainable credit schemes, subsidy programmes and digital payment facilities can improve accessibility and reduce transaction costs. Digital literacy programmes should also be organised through agricultural extension centres and farmer producer organisations to strengthen farmers' ability to use digital financial platforms effectively.

Although Financial Literacy recorded a comparatively smaller effect, its significant influence confirms that improving farmers' financial capability remains essential for informed financial decision-making. Structured financial education programmes focusing on credit management, investment planning, risk assessment and sustainable financing opportunities should be incorporated into existing agricultural extension activities. Such initiatives can improve farmers' understanding of financial products and encourage the responsible use of institutional finance.

Climate Risk Awareness also contributes significantly to Sustainable Agricultural Finance Adoption by encouraging farmers to invest in resilient agricultural practices. Climate advisory services should therefore be integrated with financial support programmes to improve farmers' understanding of climate-related risks and the financial instruments available to manage them. Strengthening institutional support, expanding digital financial systems, improving financial literacy and increasing climate risk awareness together can create an enabling



environment that encourages wider adoption of sustainable agricultural finance and supports resilient agricultural development across Kerala, Karnataka and Tamil Nadu.

5. CONCLUSION

This study examined the determinants of Sustainable Agricultural Finance Adoption among farmers in Kerala, Karnataka and Tamil Nadu by investigating the influence of Financial Literacy, Climate Risk Awareness, Digital Readiness and Institutional Support. Using a quantitative research approach and Partial Least Squares Structural Equation Modelling, the study provides empirical evidence on the factors shaping farmers' adoption of sustainable financial practices within the South Indian agricultural context. The findings confirm that all four explanatory variables have a positive and significant influence on Sustainable Agricultural Finance Adoption. Among these, Institutional Support emerged as the strongest determinant, demonstrating the importance of effective government policies, financial institutions and agricultural extension services in improving farmers' access to sustainable financial products. Digital Readiness also played a substantial role, reflecting the growing importance of digital technologies in expanding financial accessibility and service delivery. Financial Literacy and Climate Risk Awareness likewise contributed positively by strengthening farmers' financial capability and encouraging investment decisions that improve agricultural resilience. The proposed structural model demonstrated satisfactory explanatory power, predictive relevance and overall model fit, confirming its suitability for explaining Sustainable Agricultural Finance Adoption among farmers in South India. The study adds to the existing literature by integrating financial, technological, institutional and environmental dimensions within a unified analytical framework, providing a broader understanding of farmers' adoption behaviour. From a practical perspective, the findings highlight the need for coordinated efforts among governments, financial institutions and agricultural development agencies to strengthen institutional support, expand digital financial infrastructure, improve financial literacy and increase climate risk awareness. These initiatives can accelerate the adoption of sustainable agricultural finance and support resilient and environmentally sustainable agricultural development. Future research may build on this work by incorporating additional behavioural and socio-economic variables, conducting comparative studies across other regions and using longitudinal data to examine changes in adoption behaviour over time.

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