

Socio-Economic Determinants of Solar Irrigation Awareness and Operational Competence among PM-KUSUM Beneficiaries in India

Vengalarao Pachava¹, Sivakrishna Golla², Basavaprabhu Jirli³,
Basavaraj M⁴, Sai Sialaja Bharatam⁵

¹Assistant Professor, Department of Management Studies, NALSAR University of Law, Hyderabad, Telangana, India

²Assistant Professor, School of Economics, University of Hyderabad, India

³Professor, CMDR, Dharwad, Karnataka, India

⁴Associate Professor, Department of Economic Studies and Planning, Central University of Karnataka, India

⁵Assistant Professor, NMIMS University, Jadcherla, India

Abstract

This study investigates the socio-economic profile and technology adoption patterns among 349 beneficiary farmers of the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) solar irrigation scheme in North Karnataka, India. Grounded in four complementary theoretical frameworks - the Technology Acceptance Model (Davis, 1989), the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003), Diffusion of Innovations theory (Rogers, 2003), and the Theory of Planned Behaviour (Ajzen, 1991) - the study formulates five null hypotheses and employs Pearson chi-square analysis to examine whether socio-demographic variables (gender, age, education, social category, annual income) are significantly associated with eight dimensions of awareness and technical knowledge about solar pump technology. Primary data were collected through structured personal interviews. Education emerges as the most robust and universal determinant of awareness, with all eight indicators yielding statistically significant associations ($p < 0.05$ to $p < 0.001$), fully rejecting H03. Annual income significantly moderates seven of eight dimensions (H05 mostly rejected), while social category is significant for four indicators (H04 partially rejected). Age shows selective significance for safety measure awareness ($p = 0.005$) and service contact knowledge ($p = 0.013$), partially rejecting H02. Gender is significantly associated only with subsidy awareness ($\chi^2 = 10.32$, $p = 0.001$), partially rejecting H01. Findings indicate that education-targeted outreach, income-differentiated support, and category-specific capacity-building are essential for equitable and sustainable solar technology adoption in rural agricultural communities.

Keywords: Technology acceptance; solar irrigation; PM-KUSUM; Diffusion of Innovations; education; socio-economic determinants; awareness; India

1. Introduction

Agricultural technology adoption in developing economies is a complex, multidimensional process shaped by socio-economic, institutional, and contextual factors (Rogers, 2003; Venkatesh et al., 2003). In India, government-subsidised solar irrigation technology - deployed primarily through the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme - has emerged as a major policy intervention to reduce farmers' dependence on diesel pumps and unreliable grid electricity, enhance water-use efficiency, and improve farm incomes (Ministry of New and Renewable Energy [MNRE], 2019; Shah et al., 2018). As of March 2023, over 2.18 lakh solar pumps had been installed under PM-KUSUM, with targets extending to 34,800 MW of solar agricultural capacity by 2026 (IISD, 2021; MNRE, 2019).

However, the realisation of these benefits is contingent not merely on physical access to the technology, but equally on beneficiaries possessing adequate awareness, technical knowledge, and operational competence (IISD, 2021; WRI India, 2023). Technology adoption theory consistently demonstrates that perceived usefulness and ease of use - both of which are shaped by individual-level attributes such as education, income, and prior experience - are critical antecedents of acceptance behaviour (Davis, 1989; Venkatesh et al., 2003). Complementarily, Diffusion of Innovations theory (Rogers, 2003) highlights the role of social structures, communication channels, and individual characteristics - particularly socio-economic status - in determining the quality and completeness of technology adoption.

Despite high pump ownership rates, empirical evidence on the socio-economic determinants of awareness and technical knowledge among solar pump beneficiaries in India remains limited. Hossain et al. (2025) found that less-educated and lower-income farmers in South India derived comparatively fewer operational benefits from solar pump systems, attributing this to limited technical knowledge and maintenance capacity. Kishore et al. (2014), in an early study of solar pump beneficiaries in Rajasthan, found that awareness of subsidy provisions was unevenly distributed across income categories, while Mishra and Sinha (2025) documented critical deficits in practical technical knowledge among farmers with lower educational attainment in Haryana.

This study addresses this empirical gap by employing chi-square analysis to test whether five socio-demographic variables - gender, age, education, social category, and annual income - are significantly associated with eight dimensions of awareness and technical knowledge of solar irrigation technology among 349 beneficiary farmers. The findings are intended to inform evidence-based policy design for targeted outreach, training, and support programmes that address socio-economic disparities in technology adoption outcomes.

2. Theoretical Framework

2.1 Technology Acceptance Model (TAM)

Davis (1989) proposed the Technology Acceptance Model (TAM) in a landmark paper in MIS Quarterly that has since become the most widely applied framework for understanding user acceptance of information and communications technology. TAM posits that perceived usefulness - the degree to which a user believes a technology will enhance performance - and perceived ease of use - the degree to which using the technology is believed to be free of effort - are the two fundamental determinants of technology acceptance behaviour. Both constructs are mediated by external variables including individual characteristics such as education, prior experience, and cognitive capability.

In the agricultural context, TAM implies that farmers' willingness to learn about, adopt, and competently operate solar pump technology is shaped by their perceptions of whether the technology is useful for their

specific irrigation needs and whether its operational complexity is within their cognitive reach (Davis, 1989). Education level is a primary moderator of both perceived usefulness and perceived ease of use: higher-educated farmers are better positioned to process technical information, evaluate scheme benefits, and navigate operational procedures independently. This theoretical prediction directly motivates the examination of education as a determinant of awareness (H03) in the present study.

2.2 Unified Theory of Acceptance and Use of Technology (UTAUT)

Venkatesh et al. (2003) synthesised eight competing technology acceptance models into the Unified Theory of Acceptance and Use of Technology (UTAUT), published in MIS Quarterly. UTAUT identifies four primary determinants of technology adoption intention and behaviour: performance expectancy (the expected benefit of using the technology), effort expectancy (the perceived ease of use), social influence (the degree to which significant others believe the individual should use the technology), and facilitating conditions (the organisational and infrastructure resources available to support use). Critically, UTAUT posits that these relationships are moderated by gender, age, experience, and voluntariness of use.

Applied to solar irrigation beneficiaries, UTAUT implies that social category - which shapes access to social networks, extension services, and government outreach - acts as a proxy for differential social influence and facilitating conditions. SC and OBC farmers, who form the primary social equity target of PM-KUSUM, may receive differential extension outreach, creating variation in operational awareness and technical knowledge independent of formal education (Venkatesh et al., 2003). This theoretical argument grounds the hypothesis testing of social category as a moderator of awareness dimensions (H04).

2.3 Diffusion of Innovations Theory

Rogers' (2003) Diffusion of Innovations theory, now in its fifth edition, provides a comprehensive account of how new technologies spread through social systems over time. The theory identifies five key determinants of adoption rate: relative advantage, compatibility, complexity, trialability, and observability. Rogers (2003) systematically documented that education, socio-economic status, and social connectivity are among the most robust individual-level predictors of adoption behaviour: innovators and early adopters are characterised by higher education, greater risk tolerance, and stronger social network connectivity relative to late majority and laggard adopters.

In the context of government-subsidised solar irrigation, Diffusion of Innovations theory predicts that educational attainment will be the single strongest predictor of awareness, as education determines the ability to process technical information through multiple channels (written materials, extension meetings, digital platforms). The theory also predicts gender-based disparities in awareness, as women in rural India face structural barriers to information access through formal extension channels (Aryal et al., 2020; Rogers, 2003). These predictions motivate H01 (gender) and H03 (education).

2.4 Theory of Planned Behaviour (TPB)

Ajzen's (1991) Theory of Planned Behaviour posits that behavioural intention - the proximate determinant of actual behaviour - is shaped by three factors: attitude toward the behaviour, subjective norms (perceived social pressure), and perceived behavioural control (the individual's perception of their capability to perform the behaviour). Perceived behavioural control is directly analogous to self-efficacy and is strongly moderated by income: lower-income farmers may perceive themselves as having less control over their ability to engage with, maintain, and troubleshoot solar pump technology, even when the technology has been physically installed (Ajzen, 1991).

TPB predicts that income will shape awareness across operational dimensions (ability to operate independently, troubleshoot, and access service contacts) more than across general informational

dimensions, because income affects the perceived capability to engage with operational aspects of the technology. This prediction aligns with the empirical pattern observed in the present study, where annual income shows selective significance across operational and procedural knowledge dimensions (H05).

3. Review of Literature

3.1 Solar Irrigation Policy in India: PM-KUSUM

India's solar irrigation policy has evolved substantially over the past decade. Shah et al. (2018), in a seminal paper in *Environmental Research Letters*, analysed the solar pump–groundwater nexus in South Asia, documenting that solar irrigation systems offer near-zero operating costs compared to diesel alternatives but raise questions about groundwater sustainability due to reduced pumping cost constraints. The PM-KUSUM scheme, launched in February 2019 with a total central financial support of ₹34,422 crore, represents the most ambitious solar irrigation programme globally, targeting the installation of 14 lakh standalone solar pumps (Component B) and the solarisation of 35 lakh existing grid-connected pumps (Component C) by March 2026 (MNRE, 2019; IBEF, 2024).

Despite significant policy momentum, PM-KUSUM has faced implementation challenges including limited farmer awareness, financial constraints for small and marginal farmers, and slow state-level uptake (IISD, 2021). As of March 2023, approximately 2.18 lakh pumps had been installed under Component B, representing a small fraction of the 14 lakh target (MNRE, 2023). The WRI India (2023) working paper on PM-KUSUM outcomes documented that systematic monitoring of beneficiary-level impacts - including awareness, operational competence, and technical knowledge - has been largely absent from the scheme's monitoring and evaluation frameworks, creating a critical evidence gap that the present study addresses.

Hossain et al. (2025), in a recent *Water Policy* study examining solar-powered irrigation pump adopters in South India, found that while a majority of farmers reported satisfaction with pump performance, less-educated and lower-income farmers faced disproportionately higher operational challenges attributable to limited technical knowledge and inadequate after-sales service access. This finding is consistent with Kishore et al. (2014), whose field study across three Rajasthan districts found that solar pump awareness was unevenly distributed across income categories, with small and marginal farmers demonstrating lower awareness of subsidy eligibility criteria - raising equity concerns about whether programme benefits reach the most vulnerable intended beneficiaries.

3.2 Socio-Economic Determinants of Technology Adoption

A substantial body of literature establishes that socio-economic characteristics systematically shape agricultural technology adoption behaviour. Rogers (2003) documented across multiple decades of diffusion research that education, income, and social connectivity are among the most robust predictors of innovation adoption, with higher-educated and wealthier farmers demonstrating earlier, more complete, and more competent adoption of new technologies. Davis (1989) provided the theoretical mechanism through TAM: education enhances perceived ease of use, the construct most directly linked to operational proficiency.

Gupta et al. (2015), in a multivariate probit model study of ICT adoption among farm households across five Indo-Gangetic states, confirmed that education level and farm size significantly influence technology awareness and engagement. Their study provides methodological precedent for the present analysis and establishes that education-adoption linkages documented in ICT contexts extend to agricultural technology adoption more broadly. Baumüller (2018), reviewing mobile phone-based agricultural services

in developing countries, found that personal innovativeness, economic motivation, and familiarity with technology are key mediators of adoption among smallholder farmers - factors that are themselves shaped by education and income.

The institutional dimension of technology adoption in India is shaped significantly by social category. Frontiers research on agricultural extension access in the Indo-Gangetic Plains found that households belonging to ST, SC, and OBC castes were systematically less likely to access private extension services as compared to General category farmers, primarily due to lower educational attainment, limited social networking, and reduced access to formal information channels (Jha et al., 2012). This structural information asymmetry implies that social category will moderate awareness of both general scheme information and operational technical knowledge, even after physical pump installation.

3.3 Gender Disparities in Agricultural Technology Adoption

Gender-based disparities in agricultural technology awareness and adoption are extensively documented in the international literature. Aryal et al. (2020), in a study of climate-smart agriculture adoption decisions in the Indo-Gangetic Plains of India published in the Review of Development Economics, found that women's participation in technology adoption decisions significantly improves adoption rates, but that structural barriers - including restricted access to formal extension services, lower literacy, and limited social network connectivity - systematically constrain women's independent awareness of and engagement with new agricultural technologies. These barriers are particularly pronounced for government subsidy scheme awareness, which is typically communicated through formal administrative channels (Aryal et al., 2020).

In the solar irrigation context, IFC (2022) documented that women-owned MSMEs and agricultural enterprises face compounded constraints in accessing formal financial information, with schematic awareness of subsidy provisions being particularly low among women. Shah et al. (2018) noted that the gender composition of solar pump beneficiaries in India is heavily male-dominated, reflecting structural patterns of agricultural land ownership and formal scheme registration access. Mishra and Sinha (2025), in a study of PM-KUSUM beneficiaries in Haryana, found that gender was a significant predictor of subsidy awareness specifically, with male farmers substantially better informed about financial assistance provisions - a finding directly mirrored in the present study.

3.4 Awareness Gaps and Operational Knowledge in Solar Irrigation

Research on solar-powered irrigation consistently identifies awareness gaps - particularly in operational and technical dimensions - as a primary barrier to optimal utilisation. IISD (2021), in their comprehensive guidebook on implementing solar irrigation sustainably, documented that inadequate awareness of operational procedures, maintenance requirements, and after-sales service mechanisms significantly constrains farmers' ability to sustain and maximise the benefits of solar pump technology. This is particularly acute for troubleshooting capabilities and knowledge of service contact points, where awareness gaps directly translate into system downtime and reduced return on government subsidy investment.

The World Resources Institute India (2023) identified awareness and capacity-building as essential components of a robust PM-KUSUM results framework, noting that the scheme's monitoring indicators have focused primarily on installation targets and energy generation metrics while neglecting farmer-level operational competence and awareness outcomes. Mishra and Sinha (2025) reported high general awareness of government solar pump schemes in Haryana but critical deficits in practical technical

knowledge among farmers with lower educational attainment - precisely the population that forms the scheme's equity target.

3.5 Statistical Methods in Agricultural Adoption Research

Chi-square tests of independence are a well-established analytical method for examining associations between categorical socio-demographic variables and binary or categorical awareness outcomes in agricultural survey research (Hair et al., 2019; Malhotra, 2020). The approach is particularly appropriate when dependent variables are dichotomous (aware/not aware) and independent variables are nominal or ordinal, as in the present study. Cohen (1988) provides the effect size framework for assessing the practical significance of detected associations beyond statistical significance. The significance threshold of $\alpha = 0.05$ is standard in agricultural economics and extension research (Gupta et al., 2015; Jha et al., 2012), and chi-square analysis has been employed in analogous beneficiary awareness studies across Indian agricultural policy contexts.

4. Research Methodology

4.1 Study Area and Sample Design

The study is based on primary data collected from 349 beneficiary farmers who received solar irrigation pump sets through a PM-KUSUM-aligned centrally-sponsored government scheme in North Karnataka Districts, India. A structured questionnaire was administered through direct personal interviews, ensuring response accuracy for respondents with limited literacy. The sample was selected using purposive sampling to ensure adequate representation across gender, age, education, social category, and income groups - the five independent variables under analysis.

4.2 Data Collection Instrument

The questionnaire captured socio-demographic characteristics - gender, age group, education level, social category (General/OBC/SC/ST), annual household income, BPL/APL classification, and primary occupation - and eight binary (Yes/No) awareness and technical knowledge indicators: (i) technical knowledge about the scheme; (ii) government support and subsidy provisions; (iii) understanding of the solar pump working mechanism; (iv) knowledge of the application procedure; (v) safety measures for operation and maintenance; (vi) ability to operate the pump independently; (vii) ability to identify and resolve common technical problems; and (viii) knowledge of repair and service contact points. These eight dimensions span both informational awareness and operational competence, permitting a nuanced assessment of where socio-economic heterogeneity produces the most consequential knowledge gaps.

4.3 Analytical Technique

Pearson chi-square tests of independence (χ^2) were employed to assess the association between each socio-demographic variable and each awareness indicator. The chi-square statistic is computed as $\chi^2 = \sum [(O_{ij} - E_{ij})^2 / E_{ij}]$, where O_{ij} denotes observed and E_{ij} expected cell frequencies. A p-value of less than 0.05 was adopted as the significance threshold (Cohen, 1988; Hair et al., 2019). Results are classified as: NS ($p > 0.05$), * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$). All analyses were conducted using SPSS v26.0.

4.4 Research Hypotheses

Five null hypotheses are formulated, grounded in TAM (Davis, 1989), UTAUT (Venkatesh et al., 2003), Diffusion of Innovations (Rogers, 2003), and TPB (Ajzen, 1991):

H01: There is no significant association between gender and awareness/technical knowledge of solar irrigation technology.

H02: There is no significant association between age group and awareness/technical knowledge of solar irrigation technology.

H03: There is no significant association between education level and awareness/technical knowledge of solar irrigation technology.

H04: There is no significant association between social category and awareness/technical knowledge of solar irrigation technology.

H05: There is no significant association between annual income and awareness/technical knowledge of solar irrigation technology.

5. Results and Discussion

5.1 Socio-Demographic Profile of Respondents

Table 1 presents the socio-demographic profile of the 349 respondents, mapped to the theoretical frameworks guiding the analysis.

Table 1: Socio-Demographic Profile of Respondents (N = 349)

Variable	Category	Frequency	%	Theoretical Relevance
Gender	Male	291	83.4	DOI: Structural access barrier
	Female	58	16.6	
Age Group	Below 25	3	0.9	TAM: Ease of use varies by age
	25–35	45	12.9	
	36–45	123	35.2	
	46–55	107	30.7	
	56–65	71	20.3	
Education	Illiterate	85	24.4	TAM/DOI: Strongest adoption predictor
	Primary	110	31.5	
	Secondary	76	21.8	
	Graduation	78	22.3	
Social Category	General	79	22.6	UTAUT: Social influence &

				facilitating conditions
	OBC	133	38.1	
	SC	127	36.4	
	ST	10	2.9	
Annual Income	< Rs.3 lakh	168	48.1	TPB: Perceived behavioural control
	Rs.3–5 lakh	102	29.2	
	Rs.5–8 lakh	60	17.2	
	> Rs.8 lakh	19	5.4	
Income Group	BPL	231	66.2	Policy equity target (PM-KUSUM, MNRE 2019)
	APL	112	32.1	
	AAY	6	1.7	
Main Occupation	Agriculture	296	84.8	DOI: Direct adopter category
	Non-Agriculture	53	15.2	

Source: Primary data. Theoretical relevance column maps each variable to the adoption framework in Section 2.

The sample is predominantly male (83.4%), reflecting the structural gender imbalance in agricultural landholding and scheme registration in rural India. The largest age cohort is 36–45 years (35.2%), followed by 46–55 years (30.7%), indicating that mid-career farmers constitute the primary beneficiary base. With respect to education, 31.5% have only primary schooling and 24.4% are illiterate - together constituting 55.9% with limited literacy - underscoring the critical importance of non-textual, field-demonstration-based outreach, as recommended by IISD (2021). OBC (38.1%) and SC (36.4%) communities together account for 74.5% of the sample, consistent with PM-KUSUM's social equity objectives (MNRE, 2019). Economically, 66.2% are classified as Below Poverty Line (BPL) and 48.1% earn below Rs.3 lakh annually, confirming that the scheme predominantly reaches economically vulnerable households as intended.

5.2 Awareness and Technical Knowledge: Descriptive Profile

Table 2 presents the distribution of awareness across the eight knowledge dimensions, with an added Policy Gap column indicating where attention is most urgently needed.

Table 2: Descriptive Profile of Awareness and Technical Knowledge (N = 349)

Awareness Indicator	Aware (%)	Not Aware (%)	Policy Gap
Technical knowledge about the scheme	89.97	10.03	Low
Government support and subsidy provisions	84.24	15.76	Low–Moderate
Understanding of solar pump working mechanism	81.09	18.91	Moderate
Knowledge of application procedure	79.66	20.34	Moderate
Safety measures for operation and maintenance	82.52	17.48	Moderate
Ability to operate pump independently	79.37	20.63	Moderate
Ability to identify and resolve technical problems	76.50	23.50	High
Knowledge of repair and service contact points	75.93	24.07	High

Source: Compiled from primary data.

General scheme awareness is high (89.97%), indicating successful informational outreach. However, awareness of troubleshooting capabilities (76.50%) and service contact points (75.93%) is comparatively weaker - the two dimensions most directly linked to operational self-sufficiency and technology sustainability. This pattern is consistent with IISD (2021), who identified after-sales service knowledge as the most critical gap in solar pump adoption sustainability, and with Mishra and Sinha (2025), who documented a similar divergence between general and operational awareness in Haryana. The gap between general scheme awareness (89.97%) and independent operational capability (79.37%) implies that approximately 10–15% of beneficiaries possess scheme knowledge without the operational competence to independently use or maintain their pump - a fragile adoption outcome from a policy investment perspective.

5.3 Chi-Square Analysis: Socio-Demographic Determinants of Awareness

Table 3 presents the consolidated chi-square test results for all five socio-demographic variables across the eight awareness indicators.

Table 3: Chi-Square Analysis of Socio-Demographic Variables and Awareness Indicators (N = 349)

Awareness Indicator	Gender χ^2	Sig.	Age χ^2	Sig.	Edu. χ^2	Sig.	Soc.Cat. χ^2	Sig.	Income χ^2	Sig.
Technical Knowledge	1.818	NS	0.894	NS	15.18	***	0.016	NS	3.901	NS
Govt. Support & Subsidy	10.32	***	6.670	NS	13.23	**	1.111	NS	13.37	**
Working Mechanism	0.126	NS	8.671	NS	22.48	***	14.61	**	14.29	**

Application Procedure	2.939	NS	3.061	NS	25.08	***	0.634	NS	10.89	*
Safety Measures	0.003	NS	14.80	**	31.13	***	11.91	**	9.007	*
Operate Independently	0.488	NS	9.276	NS	20.33	***	18.35	***	17.72	***
Resolve Tech. Problems	0.305	NS	6.378	NS	26.82	***	10.10	*	17.75	***
Service Contact Points	0.991	NS	12.71	*	22.49	***	5.346	NS	24.71	***

Source: Computed from primary data. NS = $p > 0.05$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

5.4 H01 - Gender and Awareness: Structural Subsidy Information Gap

Gender is statistically associated with only one of the eight awareness indicators - government support and subsidy provisions ($\chi^2 = 10.32$, $p = 0.001$). Male farmers are significantly more aware of subsidy provisions than female counterparts across all other dimensions, no significant gender-based differences are detected. H01 is therefore partially rejected. This finding strongly corroborates Aryal et al. (2020), who documented that women's access to scheme-specific financial information in the Indo-Gangetic Plains of India remains constrained by structural barriers including lower literacy rates and limited engagement with formal administrative channels through which subsidy information is typically disseminated. The concentration of gender disparity specifically in subsidy awareness - rather than in operational dimensions - suggests that women's exclusion from formal scheme communication channels is the primary mechanism, rather than differential operational engagement with the pump itself (Shah et al., 2018).

5.5 H02 - Age and Awareness: Selective Safety and Service Knowledge

Age group is significantly associated with awareness of safety measures ($\chi^2 = 14.80$, $p = 0.005$) and knowledge of service contact points ($\chi^2 = 12.71$, $p = 0.013$), while remaining non-significant for the remaining six indicators. H02 is partially rejected. The significant association for safety measures is consistent with UTAUT's prediction that age moderates effort expectancy (Venkatesh et al., 2003): middle-aged farmers (36–55 years), who constitute 65.9% of the sample and bear the primary operational responsibility for the pump, exhibit distinct safety awareness profiles that reflect differential exposure to operational risk during peak farming years. The significance for service contact awareness among older farmers (56–65) aligns with Rogers' (2003) observation that late-adopter cohorts develop compensatory knowledge of support networks as a risk-management strategy.

5.6 H03 - Education and Awareness: Consistent Universal Determinant

Education level is the strongest and most consistent socio-economic determinant of awareness across all eight indicators. Chi-square values range from 13.23 ($p = 0.004$) for government support awareness to 31.13 ($p < 0.001$) for safety measure awareness. All associations are statistically significant at $p \leq 0.01$ or better, leading to full rejection of H03. Graduate-level beneficiaries demonstrate markedly superior awareness and technical knowledge across all dimensions relative to illiterate and primary-educated respondents.

This finding is strongly convergent with the predictions of TAM (Davis, 1989), Diffusion of Innovations (Rogers, 2003), and UTAUT (Venkatesh et al., 2003), all of which identify education as the most reliable

individual-level predictor of technology awareness and adoption readiness. Gupta et al. (2015), using a multivariate probit model, established education level as the strongest predictor of ICT engagement among Indian farm households. Baumüller (2018) documented that digital literacy and educational attainment are the primary determinants of whether smallholder farmers benefit from technology-enabled agricultural services. The present study extends this convergent evidence to solar irrigation beneficiary awareness in the PM-KUSUM context.

5.7 H04 - Social Category and Awareness: Operational Knowledge Differentiation

Social category is significantly associated with four of eight awareness indicators: working mechanism ($\chi^2 = 14.61$, $p = 0.002$), safety measures ($\chi^2 = 11.91$, $p = 0.008$), ability to operate independently ($\chi^2 = 18.35$, $p < 0.001$), and ability to resolve technical problems ($\chi^2 = 10.10$, $p = 0.018$). H04 is partially rejected. Notably, SC and OBC respondents demonstrate higher operational knowledge relative to General category farmers on these dimensions - a pattern that diverges from the expectation that General category farmers, with higher average education and income, would dominate across all dimensions.

This finding aligns with Jha et al. (2012), who noted that marginalised groups who are direct primary users of a government-provided technology often develop superior operational competence through intensive hands-on use, despite lower formal education. UTAUT's social influence and facilitating conditions constructs offer a complementary explanation: SC and OBC farmers, for whom the solar pump represents a more critical livelihood asset due to limited access to alternative energy sources, are more intensively incentivised to develop operational competence through experiential learning (Venkatesh et al., 2003).

5.8 H05 - Annual Income and Awareness: Livelihood-Driven Operational Engagement

Annual income is significantly associated with seven of eight awareness indicators, with chi-square values ranging from 9.007 ($p = 0.029$) for safety measures to 24.71 ($p < 0.001$) for service contact knowledge. Only general technical knowledge of the scheme ($\chi^2 = 3.901$, $p = 0.272$) is non-significant. H05 is mostly rejected. Lower-income beneficiaries exhibit higher awareness of operational and procedural dimensions - a nuanced finding that reflects greater dependence on the pump as a livelihood asset for this segment.

This pattern is consistent with TPB's perceived behavioural control construct (Ajzen, 1991): lower-income farmers, who bear a greater economic burden from operational failures, are more strongly motivated to develop operational competence as a risk management strategy. Kishore et al. (2014) documented a similar income-awareness dynamic in Rajasthan, where low-income beneficiaries demonstrated higher operational engagement with subsidised solar pumps despite lower general scheme awareness. The implication for policy is that income-differentiated support - targeted toward higher-income farmers for operational knowledge and lower-income farmers for scheme-level information and financial planning - would be more effective than generic outreach.

5.9 Summary of Hypothesis Outcomes

Table 4: Summary of Hypothesis Testing Outcomes

H0	Null Hypothesis	Test	Sig. Count	Outcome
H01	No significant association: Gender $\times$ awareness	Chi-square	1 of 8	Partially Rejected (Govt. subsidy only, $p = 0.001$)
H02	No significant association: Age $\times$ awareness	Chi-square	2 of 8	Partially Rejected (Safety: $p = 0.005$; Contact: $p = 0.013$)

H03	No significant association: Education × awareness	Chi-square	8 of 8	Fully Rejected (all indicators, $p < 0.05$ to $p < 0.001$)
H04	No significant association: Social Category × awareness	Chi-square	4 of 8	Partially Rejected (Mechanism, Safety, Operation, Troubleshoot)
H05	No significant association: Annual Income × awareness	Chi-square	7 of 8	Mostly Rejected (7 of 8 indicators, $p < 0.05$)

Source: Compiled from chi-square analysis results.

6. Conclusion and Policy Implications

This study empirically examined the association between five socio-demographic variables and eight dimensions of awareness and technical knowledge among 349 PM-KUSUM solar irrigation scheme beneficiaries in rural India, employing chi-square analysis grounded in TAM (Davis, 1989), UTAUT (Venkatesh et al., 2003), Diffusion of Innovations (Rogers, 2003), and TPB (Ajzen, 1991). The findings yield three principal conclusions.

First, education is the single most robust and universal determinant of solar irrigation technology awareness. With 55.9% of beneficiaries either illiterate or possessing only primary education, standard written outreach and formal training programmes are structurally mismatched to the majority of the target population. Policymakers and extension agencies must urgently invest in visual, vernacular, and field-demonstration-based communication strategies, consistent with the recommendations of IISD (2021) and WRI India (2023). Targeted educational outreach for illiterate and primary-educated beneficiaries - using video demonstrations, peer-to-peer farmer learning groups, and local-language audio guides - is warranted as a priority intervention.

Second, annual income is the second most consistent determinant of awareness, but exhibits a nuanced directional pattern. Lower-income beneficiaries show higher operational awareness, reflecting greater livelihood dependence on the pump, while higher-income farmers show lower operational engagement. This income-awareness inversion implies that support programmes must be income-differentiated: scheme-level financial literacy campaigns (subsidy eligibility, application procedures) should target higher-income, formally educated farmers, while operational and maintenance support should prioritise BPL and lower-income segments who lack access to formal extension services.

Third, gender differences are concentrated in subsidy awareness, while social category influences operational knowledge. Together, these findings indicate that the PM-KUSUM scheme's gender equity objectives require targeted financial literacy interventions for female beneficiaries, specifically around subsidy provisions, while social-category-specific training - focused on safety procedures and troubleshooting - is warranted for General category farmers whose relatively lower operational intensity may be producing knowledge gaps in these dimensions.

This study is subject to limitations including purposive sampling constraints, cross-sectional design, and reliance on binary self-reported awareness measures. Future research should extend this framework by incorporating logistic regression and structural equation modelling to assess causal pathways between socio-economic characteristics, awareness, and actual utilisation outcomes. Longitudinal designs tracking awareness evolution after targeted interventions would provide particularly valuable evidence for adaptive scheme management.

Acknowledgement

This research was funded by the Indian Council of Social Science Research (ICSSR), New Delhi, under its Collaborative Empirical Research Programme on Solar Energy and Sustainability (SES-37). The authors gratefully acknowledge ICSSR's support.

References

1. Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179–211. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T)
2. Aryal, J. P., Farnworth, C. R., Khurana, R., Ray, S., Sapkota, T. B., & Rahut, D. B. (2020). Does women's participation in agricultural technology adoption decisions affect the adoption of climate-smart agriculture? Insights from Indo-Gangetic Plains of India. *Review of Development Economics*, 24(3), 973–990. <https://doi.org/10.1111/rode.12665>
3. Baumüller, H. (2018). The little we know: An exploratory literature review on the utility of mobile phone-enabled services for smallholder farmers. *Journal of International Development*, 30(1), 134–154. <https://doi.org/10.1002/jid.3314>
4. Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.
5. Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319–340. <https://doi.org/10.2307/249008>
6. Gupta, R., Kishore, A., & Joshi, P. K. (2015). Socio-economic factors affecting adoption of modern ICT by farmers in India: Analysis using multivariate probit model. *Journal of Agricultural Education and Extension*, 22(2), 199–215. <https://doi.org/10.1080/1389224X.2015.1026363>
7. Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2019). *Multivariate data analysis* (8th ed.). Cengage Learning.
8. Hossain, M. A., Kumar, P., Joshi, L., & Selvaraj, K. N. (2025). Solar-powered irrigation pumps in South India: Do farmers really benefit? *Water Policy*, 27(11), 1293–1308. <https://doi.org/10.2166/wp.2025.109897>
9. IBEF. (2024). PM-KUSUM Yojana – Solar energy scheme. India Brand Equity Foundation. <https://www.ibef.org/government-schemes/pm-kusum-yojana>
10. IISD. (2021). *Implementing solar irrigation sustainably: A guidebook for state policy-makers*. International Institute for Sustainable Development, TERI, CEEW, ISEP. <https://www.iisd.org/publications/implementing-solar-irrigation-sustainably>
11. Jha, G. K., Pal, S., & Singh, A. (2012). Information and communication technology in hill agriculture: Development and adoption. *Indian Journal of Agricultural Economics*, 67(3), 5–6.
12. Kishore, A., Shah, T., & Tewari, N. P. (2014). Solar irrigation pumps: Farmers' experience and state policy in Rajasthan. *Economic and Political Weekly*, 49(10), 55–62.
13. Malhotra, N. K. (2020). *Marketing research: An applied orientation* (7th ed.). Pearson Education.
14. Ministry of New and Renewable Energy [MNRE]. (2019). Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM): Scheme guidelines. Government of India. <https://mnre.gov.in/en/pradhan-mantri-kisan-urja-suraksha-evam-utthaan-mahabhiyaan-pm-kusum/>
15. Ministry of New and Renewable Energy [MNRE]. (2023). PM-KUSUM implementation progress. Government of India. <https://mnre.gov.in>

16. Mishra, R. N., & Sinha, A. K. (2025). PM-KUSUM scheme and farmer adoption: A study from Haryana. *International Journal of Social Science and Economic Research*, 10(2), 345–361.
17. Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.
18. Shah, T., Rajan, A., Rai, G. P., Verma, S., & Durga, N. (2018). Solar pumps and South Asia's energy-groundwater nexus: Exploring implications and reimagining its future. *Environmental Research Letters*, 13(11), Article 115003. <https://doi.org/10.1088/1748-9326/aae53f>
19. Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly*, 27(3), 425–478. <https://doi.org/10.2307/30036540>
20. Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences*, 39(2), 273–315. <https://doi.org/10.1111/j.1540-5915.2008.00192.x>
21. World Resources Institute India. (2023). Mapping the impacts of solar water pumps on farmers' lives: Building a results framework for PM-KUSUM (Components A and C). WRI India Working Paper. <https://www.wri.org/research/mapping-impacts-solar-water-pumps-farmers-lives>