

Economic Viability and Adoption Constraints of Stand-Alone Solar Irrigation Pumps under PM-KUSUM: Evidence from Uttar Pradesh, India

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ABSTRACT

This study assesses the economic viability of stand-alone solar pumps (2 HP, 3 HP, 5 HP, and 7.5 HP) under Component B of India's PM-KUSUM scheme, using primary survey data from 84 adopters in diesel-reliant Bahraich district, Uttar Pradesh, an aspirational district with high tube-well dependency (58.1% irrigated area). Replacing 6.5-8 HP diesel pumps, which incur annual fuel costs of ₹48,169.95, the analysis reveals superior performance for smaller capacities: 2 HP offers the shortest payback period (1.69 years), highest NPW (₹4,87,898.87 at 7% discount), IRR (36.41%), and Benefit-Cost Ratio (7.64), while 7.5 HP lags with 5.61 years payback,

₹3,60,232.38 NPW, 31.43% IRR, and 2.79 BCR due to elevated upfront costs (₹69,205–₹1,77,638 farmer share). Friedman tests on constraints (Chi-square 315.587 pre-installation, $p < 0.001$; 180.873 post-installation, $p < 0.001$) highlight significant disparities, with top pre-installation barriers as inconvenient repayment methods, installation delays, and lengthy applications; post-installation issues prioritize theft risks, slow complaint resolution, and filing difficulties. Findings advocate policy enhancements like Gramya Urja Nari training for women, Solar Sakhi peer education, Panchayat Green Energy Desks, and BIS quality standards to boost adoption among small-holders, curb diesel reliance, and foster sustainable agriculture.

Keywords Internal rate of return, Net present worth, Payback period, PM KUSUM scheme, Solar irrigation pump.

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INTRODUCTION

Agriculture in India continues to face several challenges that directly affect the livelihoods and well-being of farming households. Low farm earnings, rising indebtedness, crop losses, uncertain weather conditions, and inadequate irrigation facilities remain major concerns for farmers. According to the NSSO's 2011–12 Consumption Expenditure Survey, more than one-fifth of rural households dependent

on self-employed farming were still living below the poverty line. The average Monthly Per-capita Consumption Expenditure (MPCE) in India of food and non-food in rural areas is 1,939 Rs, with 47.04% share in MPCE and 2,183 Rs. With 52.96% share in MPCE, respectively (NSSO 2023). These challenges not only affect the economic security of farm families but also raise concerns about the long-term sustainability of Indian agriculture, and it remains an important part of the Indian economy, contributing around 16 percent to GDP and providing livelihoods to nearly half of the population (Economic Survey 2024–25). Irrigation essential for improving and stabilizing farm production, is largely dependent on nearly 30 million sets of electric and diesel pumps. These pumps account for a considerable share of energy use, consuming about 20 percent of total electricity and nearly 12 percent of diesel used in the country (Srinivas 2018). The government also spends nearly ₹500 billion annually on agricultural subsidies to support this irrigation system (Bhati *et al.* 2019). Despite the expansion of rural electrification, unreliable electricity supply in many areas continues to force farmers to depend on diesel pumps. This increases the cost of irrigation and places an additional burden on both farmers and the government.

Solar irrigation pumps have evolved as a promising alternative to conventional irrigation systems. Solar pumps use renewable energy and can reduce farmers' dependence on diesel and unreliable grid electricity. Apart from lowering recurring irrigation costs, they also offer environmental benefits by reducing the use of fossil fuels. Experiences from countries such as China and the United States indicate the potential of solar irrigation to reduce energy costs and support more sustainable agricultural production. In India, replacing just one million diesel pumps with solar pumps could potentially save around nine billion litres of diesel and foreign exchange worth about USD 4.5 billion over their lifetime (KPMG 2014). Recognizing these potential benefits, the Indian government introduced the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) and approved it on February 19, 2019. The scheme aims to promote renewable energy in agriculture, reduce dependence on conventional energy sources, lower the burden of power subsidies, and contribute

to improving farmers' incomes.

The issue is particularly relevant in Uttar Pradesh, which has one of the largest irrigated areas in the country, covering around 14 million hectares. Despite this extensive irrigation coverage, farmers in the state continue to face problems related to outdated irrigation technologies, irregular electricity supply, high input costs, floods, droughts, and inadequate coordination among different stakeholders. These constraints are particularly important in regions such as Eastern Uttar Pradesh, Central Uttar Pradesh, and Bundelkhand, where agricultural production remains vulnerable to water and energy-related challenges (Nair *et al.* 2013, Umar 2020). Major crops are affected by these constraints. Although Uttar Pradesh ranks fourth in the country in terms of solar pump installations under PM-KUSUM, with 58,926 installed units, the level of adoption remains limited in relation to the potential demand, particularly among small and marginal farmers.

Existing studies on solar irrigation have largely focused on issues such as policy support, regional differences, energy savings, and environmental benefits. However, comparatively limited attention has been given to the viability of economic of solar irrigation pumps with different capacities under the specific conditions of Uttar Pradesh. The choice of pump capacity is important because a larger pump does not necessarily mean greater economic benefits for a farmer. The initial investment, operating requirements, landholding size, irrigation needs, and expected savings can all influence the economic feasibility of a solar pump. Therefore, assessing different pump capacities is necessary to understand which options are economically suitable for farmers.

The present study evaluates the economic viability of stand-alone solar irrigation pumps of 2 HP, 3 HP, 5 HP, and 7.5 HP under Component B of the PM-KUSUM scheme in Uttar Pradesh. The study has two major objectives. First, it assesses the economic feasibility of different solar pump capacities using indicators such as Net Present Worth (NPW), Internal Rate of Return (IRR), Benefit-Cost (B:C) ratio, and Payback Period. Second, it examines the major constraints faced in the implementation and adoption

of PM-KUSUM and suggests appropriate policy measures for improving the effectiveness of the scheme.

MATERIALS AND METHODS

Study Area and Sampling

The survey was conducted in the Bahraich district of Uttar Pradesh. It was purposively selected because this region has recently been included in the Aspirational District Programme, launched in 2018, which aims to promote development across several sectors, including agriculture and water resources. Bahraich district is covered under this programme. Irrigation in the district is mainly dependent on tube wells and wells. During 2021–22, tube wells and wells accounted for 58.1% and 36.07% of the total irrigated area in the district, respectively. Among tube wells, private tube wells accounted for a substantially larger share (55.7%) compared to state-owned tube wells (2.4%) (District Statistical Journal, Bahraich, 2021–22). The district also shows a strong dependence on diesel-powered irrigation pumps. According to the District Statistical Journal, Bahraich (2022–23), there were 72,323 diesel-operated pumps in the district, compared with only 328 electricity-operated pumps. This large difference indicates that irrigation activities in Bahraich predominantly rely on diesel as an energy source, resulting in substantially higher diesel consumption for irrigation than for electricity. The region primarily cultivates major crops such as paddy, maize, wheat, and sugarcane, mostly water-loving crops.

To accomplish the study objectives, an initial step involved the selection of six blocks, namely Kaisarganj, Fakharpur, Chittaura, Payagpur, Shivpur, and Mihinpurwa, within the Bahraich district. Using a multistage sampling technique, two villages were selected from each block, followed by the selection of 10 farmers from each village. As a result, a total sample size of 120 farmers was obtained. Out of the total respondents, 84 farmers who had installed and were using solar irrigation pumps were selected through the snowball sampling method (Gautam and Singh 2021). The remaining 36 respondents were selected using random sampling. The survey schedule was prepared for the collection of primary data. A thorough survey was undertaken using a properly structured schedule

during the period 2023–24.

Empirical Methodology

To examine the economic viability of solar irrigation pumps, the following economic criteria were employed (Gautam *et al.* 2020, Kumar *et al.* 2023).

a) Payback period

$$P = \frac{I}{E}$$

Where,

P = Payback period (years)

I = Investment of the project (in Rs.)

A = Annual net cash revenue (in Rs.)

b) Net Present Worth

$$NPW = \frac{P_1}{(1+i)t_1} + \frac{P_2}{(1+i)t_2} + \frac{P_3}{(1+i)t_3} + \dots + \frac{P_n}{(1+i)t_n} - C$$

Where,

P = Net cash flow in nth year (years)

i = Discount rate, t = time period (years)

C = Initial cost of investment

c) Internal rate of Return

$$IRR = \left[\begin{array}{c} \text{Lower} \\ \text{discount} \\ \text{rate} \end{array} \right] + \left[\begin{array}{c} \text{Difference} \\ \text{between the} \\ \text{two discount rate} \end{array} \right] \times \left[\begin{array}{c} \text{Present worth of} \\ \text{Cash flow at lower} \\ \text{discount rate} \\ \hline \text{Absolute difference between} \\ \text{the present worths of the cash flow} \\ \text{at the two discount rate} \end{array} \right]$$

d) B-C ratio

$$B-C \text{ ratio} = \frac{\sum_{t=1}^n \frac{B_t}{(1+r)^t}}{\sum_{t=1}^n \frac{C_t}{(1+r)^t}}$$

Where,

B_i = Present worth of cash flow

C_i = Present worth of Cost

r = rate of interest

n = number of years

e) Constraints

Friedman test:

The Friedman test was used to examine whether significant differences existed among the treatments or alternatives being compared. In the present study, the test was used to analyse and rank the constraints faced by respondents according to their relative importance. It helped determine whether the differences in the respondent's rankings of various constraints were statistically significant. Thus, rather than examining individual constraints separately, the Friedman test provided an overall assessment of the relative significance of different constraints (Lal *et al.* 2016).

The following hypothesis was tested for the constraints as follows:

H0 (Null Hypothesis): There is no significant constraints among farmers regarding the constraints faced by respondents during the online procedure and before installation & during and after installation.

H1 (Alternative Hypothesis): There is significant constraints among farmers regarding the constraints faced by respondents during the online procedure and before installation & during and after installation.

The formula for the Friedman test statistic is:

$$Fr = \frac{12}{nk(k+1)} (T_1^2 + T_2^2 + \dots + T_k^2) - 3n(k+1)$$

Where:

n is the number of blocks (datasets)

k is the number of treatments or classifiers

T is the treatment or classifier

The Friedman test statistic follows a chi-square

distribution with $(k-1)$ degrees of freedom under the null hypothesis of no difference in performance among the treatments or classifiers. (Shukla *et al.*, 2024).

RESULTS AND DISCUSSION

Economic viability

In the study area, the farmers relied on 6.5 HP and 8 HP diesel pumps for irrigation, consuming an average of 48,169.95 Rs. per liter/year/farm. With the shift to different HP, like 2 HP, 3 HP, 5 HP, and 7.5 HP solar irrigation pumps, diesel expenses were eliminated, resulting in a direct saving of 48,169.95 Rs. per year. This saved amount was considered the incremental benefit and used to assess the economic viability of all HP solar irrigation pump.

Payback period

The payback period analysis was carried out for solar irrigation pumps with capacities of 2 HP, 3 HP, 5 HP, and 7.5 HP. The installation cost borne by farmers was estimated at ₹69,205.2 for the 2 HP pump, ₹92,633.2 for the 3 HP pump, ₹130,999.2 for the 5 HP pump, and ₹177,637.6 for the 7.5 HP pump.

As shown in Table 1, the investment in the 2 HP solar irrigation pump could be recovered within 1.69 years, representing the shortest payback period among all the pump capacities considered. The investment in the 3 HP pump could be recovered within 2.58 years, while the payback period for the 5 HP pump was 4.35 years. The 7.5 HP solar irrigation pump recorded the longest payback period of approximately 5.61 years, mainly due to its higher initial investment cost. Overall, the findings indicate that smaller-capacity solar irrigation pumps provide a faster recovery of investment and are relatively more financially attractive to

Table 1. Payback period of Solar irrigation pumps.

SL. No.	HP	Payback period (Years)
1	2	1.69
2	3	2.58
3	5	4.35
4	7.5	5.61

Table 2. Net Present Worth of solar irrigation pump.

SL No.	HP	NPW (Rs.)
1	2	4,87,898.87
2	3	4,64,251.54
3	5	4,21,371.86
4	7.5	3,60,232.38

farmers than larger-capacity pumps.

Net Present Worth (NPW)

The primary economic benefit of installing a solar irrigation pump was the savings on diesel, estimated at 48,169.95 Rs. liter per year per farm. In the first five years, the farmers incurred no maintenance costs, as any repairs were covered under the manufacturer's warranty. After that, the initial repair and maintenance cost for the solar pump was different for different HPs, like for 2 HP it was 500 Rs., for 3 HP, 5 HP, and 7.5 HP it was 600 Rs., 1000 Rs., and 2000 Rs. respectively. These initial costs will increase by 10% compoundly.

Table 2 shows that the net present worth (NPW) of 2 HP was calculated at 4,87,898.87 Rs. This was followed by the 3 HP solar pump with a net present worth of 4,64,251.54 Rs., and then the 5 HP solar pump with 4,21,371.86 Rs. The lowest net present worth was observed for the 7.5 HP solar pump, which is 3,60,232.38 Rs. All these estimations were made at a 7% discount rate.

Internal Rate of Return (IRR)

Table 3 in the appendix presents the calculation of the internal rate of return (IRR) for all HP solar irrigation pumps. For the lower discount rate of 7%, the net present worth (NPW) was calculated for all HPs individually, and for the higher discount rate of 30%, the NPW was calculated. By the analysis, it was

Table 3. Internal Rate of Return of Solar Irrigation Pump.

SL. No.	HP	IRR (%)
1	2	36.41
2	3	35.40
3	5	33.69
4	7.5	31.43

Table 4. Benefit Cost Ratio of solar irrigation pump.

SL. No.	HP	BCR
1	2	7.64
2	3	5.78
3	5	4.01
4	7.5	2.79

observed that the internal rate of return (IRR) for the 2 HP solar irrigation pump was 36.41%, which was the highest among all. For the 3 HP pump, the IRR was estimated at 35.40%, followed by 33.69% for the 5 HP pump. In the case of the 7.5 HP solar irrigation pump, the IRR was comparatively lower at 31.43%.

Benefit-cost ratio

Table 4 presents the Benefit-Cost (B-C) ratios of solar irrigation pumps with different capacities. Among the pumps considered, the 2 HP solar irrigation pump recorded the highest B-C ratio of 7.64, indicating that it was the most economically viable option for farmers. The 3 HP solar pump ranked second, with a B-C ratio of 5.78. The B-C ratio decreased with an increase in pump capacity, falling to 4.01 for the 5 HP pump and 2.79 for the 7.5 HP pump. Overall, the findings suggest that smaller-capacity solar irrigation pumps, particularly the 2 HP and 3 HP models, were more economically viable and financially attractive to farmers than larger-capacity pumps.

Constraints faced by respondents

In the present study, the Friedman test was used to analyse the constraints faced by farmers at different stages of the PM-KUSUM scheme. The test was applied to determine whether statistically significant differences existed in the rankings assigned to the various constraints by the same group of respondents. Since the responses were recorded in the form of ordinal rankings, the Friedman test was considered appropriate as a non-parametric method for analyzing related samples.

In simple terms, the Friedman test helps determine whether farmers considered some constraints to be significantly more important or severe than others. It therefore provides a statistical basis for

Table 5. Constraints faced by respondents during the online procedure and before installation in the study area.

Constraints	Not sever	Sever	Most sever	Mean	Friedman Mean rank	Overall Rank
Application procedures and formalities are lengthy.	51	21	12	1.56	6.36	III
The rate of interest prescribed on the loan is excessively high.	66	16	2	1.24	5.46	IV
The maturity period of the loan is too short.	78	3	3	1.11	4.86	V
Excessive collateral is demanded, making it difficult for borrowers.	83	1	0	1.01	4.57	IX
Repayment methods offered by banks are inconvenient, adding complexity to the loan repayment process for rural farmers.	31	6	47	20.9	7.90	I
Despite seeking financial assistance, I have not experienced any notable improvement in my income.	83	2	0	1.01	4.58	VII
The inconvenient location of banks hinders accessibility, making it difficult for rural farmers to reach the bank.	79	1	4	1.11	4.83	VI
There is no exposure of mass media by farmer.	84	0	0	1.00	4.51	X
There is no interaction between extension officer and farmer.	83	1	0	1.01	4.55	VIII
The installation of solar panels takes too much time.	37	13	34	1.96	7.39	II

identifying and ranking the major problems faced by farmers during the implementation and adoption of the PM-KUSUM scheme.

Constraints faced by respondents during the online procedure and before installation (Table 5)

Repayment methods are inconvenient: This was the most severe constraint during the pre-installation phase. The repayment systems were seen as complex and inconvenient, adding financial stress.

Installation of solar panels takes too much time: Delay in the installation process emerged as the second most important constraint, frustrating farmers expecting quick implementation.

Application procedures and formalities are lengthy: A considerable number of respondents found the application and documentation process to be lengthy and complicated. This indicates procedural delays as a significant hurdle in accessing benefits under the scheme.

Rate of interest on loan is excessively high: Although not the topmost concern, some farmers felt the interest rates prescribed were high, making loan

repayment burdensome.

Maturity period of loan is too short: A short maturity period was reported by respondents as a constraint, putting pressure on farmers to repay the loan faster than manageable.

Inconvenient bank locations: Physical access to banks was difficult for many farmers, resulting in additional hurdles in financial transactions.

No notable improvement in income after financial assistance: Some respondents did not observe significant income changes despite receiving loans, suggesting inefficiencies in the scheme's implementation.

No interaction with extension officers: Minimal interaction with extension officers was reported, suggesting a lack of field-level support and guidance.

Excessive collateral demand: Farmers reported that banks often asked for excessive collateral, discouraging many from availing loans.

No exposure to mass media: A significant number of farmers reported no mass media exposure, high-

Table 6. Test statistics of the Friedman test of constraints in online procedure and before installation.

Test statistics		Value
N		84
Chi-square		315.587
df		9
Asymp. Sig.		0.000
Monte Carlo Sig.	Sig	0.000
99% Confidence interval	Lower Bound	0.000
	Upper Bound	0.000

lighting the lack of awareness programs related to solar installations.

Table 6 presents the results of the statistical analysis of constraints faced by farmers during the online application and pre-installation stages of the PM-KUSUM scheme. The analysis, based on responses from 84 respondents, yielded a Chi-Square value of 315.587 with 9 degrees of freedom. The corresponding p-value was less than 0.01, indicating that the differences in the rankings assigned to various constraints were statistically significant at the 1% level of significance. The Monte Carlo significance test further supported this result, confirming the statistical significance of the observed differences.

The findings indicate that farmers did not perceive all constraints with equal severity. Instead, significant differences existed in the importance assigned to different problems, suggesting that some constraints were considered more serious than others

during the online application and pre-installation stages.

Based on the ranking of constraints, inconvenient repayment methods, lengthy application procedures, and delays in the installation of solar panels emerged as the most critical problems faced by farmers during this phase.

Constraints faced by respondents during and after installation (Table 7)

Installed equipment may be stolen: The most severe constraint during/after installation was the fear of theft of installed solar equipment. This concern created anxiety and insecurity among farmers.

Delay in complaint resolution: The second-highest ranked constraint was the excessive time taken to resolve complaints, leading to frustration and loss of trust in service providers.

Problems in filing complaints: Difficulty in registering complaints was one of the major challenges faced after installation.

Premature equipment breakdown: Equipment breaking down before the expected lifespan further burdened farmers with maintenance issues and financial loss.

Others receiving better quality equipment at same price: Farmers observed quality discrepancies for the same price among different beneficiaries, indi-

Table 7. Constraints faced by respondents during and after installation.

Constraints	Not sever	Sever	Most sever	Mean	Friedman Mean score	Overall Rank
Farmers do not receive high-quality equipment.	44	20	20	2.15	4.91	VII
Not all farmers are getting better quality at the same price.	28	26	30	2.24	5.26	V
Not able to file complaints easily.	3	28	53	2.60	6.54	III
Not all equipment reaching to farmer.	29	46	9	2.25	5.25	VI
Lack of insurance facility.	32	34	18	1.86	4.15	IX
Risk of stolen.	3	4	77	2.88	7.58	I
Complaint is not resolved quickly.	0	23	61	2.73	6.95	II
Equipment is breaking down prematurely.	13	25	46	2.39	5.89	IV
Contractor is not doing the installation correctly.	34	18	32	1.95	4.62	VIII
Lack of receiving a warranty card from the government or the company.	27	50	7	1.76	3.84	X

Table 8. Test statistics of the Friedman test of constraints in during and after installation.

Test statistics		Value
N		84
Chi-square		180.873
df		9
Asymp. Sig.		0.000
Monte Carlo Sig.	Sig	0.000
99% Confidence interval	Lower Bound	0.000
	Upper Bound	0.000

cating concerns of inequality and unfair practices.

Not all equipment reaching farmer: Some reported that not all promised equipment parts were delivered, which compromised the functioning of solar pumps.

Low-quality equipment delivered: Some respondents received equipment that was perceived to be of poor quality, affecting the efficiency of the solar pumps.

Contractor doing installation properly: Some farmers raised concerns about improper installation by contractors, affecting the system's long-term performance.

Getting insurance facility: Lack of clear insurance coverage for the installed equipment was noted, leaving farmers vulnerable to losses.

Warranty card provided by government/company: The provision of warranty cards was relatively better managed, but they still needed improvement in clarity and availability.

Table 8 presents the results of the statistical analysis of constraints faced by farmers during and after the installation of solar irrigation pumps. Based on the responses of 84 participants, the analysis yielded a Chi-square value of 180.873 with 9 degrees of freedom. The corresponding p-value was less than 0.01, indicating that the differences in the rankings of the constraints were statistically significant at the 1% level of significance. The Monte Carlo significance test further supported these findings, providing strong evidence to reject the null hypothesis.

The results indicate that farmers did not per-

ceive all constraints with equal severity. Significant differences existed in the importance assigned to the various constraints, suggesting that certain problems were considered more serious than others during and after the installation phase.

According to the ranking results, the possibility of theft of installed equipment, delays in resolving complaints, and difficulties in filing complaints emerged as the most severe constraints faced by farmers. These findings highlight important operational and security-related challenges associated with the use and management of solar irrigation pumps after their installation.

Suggestions for improvement in the scheme

Based on the constraints identified during the study, the following suggestions are proposed to enhance the effectiveness, accessibility, and impact of the PM KUSUM scheme:

Gramya Urja Nari (GUN) Initiative

Launch the Gramya Urja Nari (GUN) program, aiming to train rural women in basic repair, maintenance, and troubleshooting of solar irrigation pumps.

Women selected under the GUN program can be certified after completing short technical courses organized at the block or district level.

This will not only create local technical support systems but also promote women's empowerment and employment in the renewable energy sector.

Solar Sakhi (Solar Ally/Friend) Program

Introduce the Solar Sakhi program, where trained rural youth and especially women will act as solar energy ambassadors.

Their role would include:

Educating farmers about the benefits of green energy and solar irrigation.

Demonstrating the advantages of adopting new tech-

nologies like the Universal Solar Pump Controller (USPC) to use solar panels for different works as chaff cutter, floor mill, cold storage, enhances the efficiency of solar systems.

Inspiring peer farmers to shift towards sustainable and environment-friendly practices.

Solar Sakhis can be provided with modest honoraria and training support from government or NGO partnerships.

Green Energy Desks

A dedicated Green Energy Help Desk should be established in every Panchayat office.

Services offered would include:

Providing information about all government schemes related to renewable energy, including PM KUSUM.

Assisting farmers in filling online applications, issue resolution, and subsidy tracking.

Educating villagers about new technologies, maintenance support contacts, and insurance details.

Quality Standards for Solar Irrigation Equipment

Set up mandatory national quality standards for all components of solar irrigation pumps as panels, motors, controllers, and structures.

Only suppliers and contractors meeting the Bureau of Indian Standards (BIS) or equivalent quality marks should be allowed to participate.

This would eliminate the dual-quality problem, ensuring uniform product reliability and farmer satisfaction across regions.

CONCLUSION

This study clearly demonstrates the economic viability of solar irrigation pumps as a game-changer for farmers in diesel-reliant areas under the PM-KUSUM scheme. By replacing 6.5-8 HP diesel pumps, which cost around ₹48,169.95 annually in fuel, solar models

deliver immediate savings with no ongoing diesel expenses, forming the backbone of their financial appeal. Smaller capacities like the 2 HP pump stand out, recovering their modest ₹69,205.25 installation cost in just 1.69 years, boasting the highest net present worth of ₹4,87,898.87 at a 7% discount rate, an impressive internal rate of return of 36.41%, and a benefit-cost ratio of 7.64. The 3 HP follows closely with a 2.58 year payback, ₹4,64,251.54 NPW, 35.40% IRR, and 5.78 B-C ratio, while mid-range 5 HP and larger 7.5 HP options, despite positive returns of 4.35 years payback, ₹4,21,371.86 NPW, 33.69% IRR, 4.01 B-C for 5 HP, and 5.61 years, ₹3,60,232.38 NPW, 31.43% IRR, 2.79 B-C for 7.5 HP, face longer waits due to steeper upfront costs starting at ₹1,30,999 and ₹1,77,638 respectively. Low maintenance needs, free for the first five warranty years and then modest at ₹500-2,000 annually (escalating 10% compound), further solidify solar as a sustainable upgrade over diesel.

However, Friedman tests on 84 respondents uncover stark, statistically significant differences in constraints (Chi-square values of 315.587 and 180.873, $p < 0.001$ for pre- and post-installation phases), revealing uneven hurdles that hinder adoption. Before installation, inconvenient repayment methods topped concerns, followed by lengthy delays in panel setup and cumbersome applications, compounded by high loan interest, short maturities, remote banks, poor extension support, and low media awareness. After installation, theft risks loomed largest, trailed by slow complaint resolutions, filing difficulties, premature breakdowns, quality inconsistencies, incomplete deliveries, shoddy contractor work, missing insurance, and warranty gaps. These ranked priorities show farmers perceive some barriers as far more crippling than others, underscoring operational and procedural flaws despite economic promise.

In essence, solar pumps offer compelling financial and environmental wins, particularly for smallholders, but realizing PM-KUSUM's full potential requires streamlining access and post-setup safeguards to build trust and scale uptake.

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