

CONSTRAINTS TO SOLAR PHOTOVOLTAIC IRRIGATION PUMP ADOPTION IN THE CAUVERY DELTA REGION OF TAMIL NADU: A RESPONSE PRIORITY INDEX APPROACH

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ABSTRACT

Understanding why farmers do not adopt solar photovoltaic (SPV) irrigation pump sets despite substantial government financial support is critical for designing effective intervention programs under India's PM-KUSUM scheme. This study investigates the constraints to solar pump adoption among 180 non-adopting farm households, drawn from a total sample of 360 farm households across 18 villages in the Cauvery Delta Region (CDR) of Tamil Nadu encompassing Mayiladuthurai, Tiruvarur, and Thanjavur districts during 2023–24. The Response Priority Index (RPI), a rank-based quotient (RBQ) technique (Sabarathnam, 1988), was applied to prioritize 17 adoption constraints identified through focus group discussions and a review of prior literature. High initial capital cost ranked first in perceived importance (38.9% of respondents placed it at Rank 1), followed in descending priority by inadequate PM-KUSUM awareness, the free electricity distortion wherein Tamil Nadu's zero-tariff agricultural power policy makes solar investment unattractive relative to free electric irrigation, inadequate after-sales service, and lack of institutional credit access. The RPI-based priority order was broadly consistent with Garrett's Ranking results reported in comparable CDR studies (Jayakumar and Ramasamy, 2019). The study concludes that solar pump adoption constraints in the CDR are simultaneously economic, informational, and structural in nature indicating the need for coordinated economic, informational and institutional policy interventions. Recommended interventions include net metering for solar pump systems to neutralize the free electricity distortion, NABARD zero-interest solar pump loans, intensive district-level PM-KUSUM awareness campaigns, expansion of authorized service center networks, and tenant farmer eligibility reforms under PM-KUSUM.

KEYWORDS: Solar irrigation pumps; adoption constraints; Response Priority Index; rank-based quotient; PM-KUSUM; free electricity distortion; Cauvery Delta Region; Tamil Nadu

INTRODUCTION

Solar photovoltaic (SPV) irrigation pump sets have emerged as a transformative technology for smallholder agriculture in India, offering grid-independent irrigation with low operating energy costs and reduced dependence on conventional fuel-based pumping. The Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme, launched in 2019 with total central financial support of Rs. 34,422 crore and a target of 30.8 GW of solar capacity by March 2026, provides Central Financial Assistance (CFA) of 30 per cent of the benchmark or tender cost, whichever is lower, for Components B and C in general states, with the respective State/UT required to provide at least 30 per cent financial support. Despite this progress, Tamil Nadu lags significantly behind Gujarat, Rajasthan, and Maharashtra in solar pump penetration, with approximately 1,28,000 installations against a total pump universe of 27.36 lakh pump sets (4.7% penetration).

The Cauvery Delta Region (CDR) of Tamil Nadu, comprising Thanjavur, Tiruvarur, and Mayiladuthurai districts, is one of India's most productive irrigated agricultural landscapes, producing approximately 40 per cent of Tamil Nadu's paddy output from a triple-cropping system (Kuruva, Samba, and Navarai seasons). The CDR hosts approximately 4,34,050 energised pump sets, of which 3,28,970 are grid-connected electric pumps under TANGEDCO's free-power scheme, 83,233 are diesel pump sets, and 21,847 are solar pump sets (5.0% penetration as of March 2024). The coexistence of three pump types each with distinct energy economics and adoption dynamics creates an analytically rich context for constraint investigation.

A structurally distinctive feature of CDR agriculture is Tamil Nadu government's free electricity policy for agricultural pump connections, introduced in 2003. Registered TANGEDCO agricultural pump users pay zero electricity tariff, with all costs borne by the state exchequer at an estimated Rs. 8,200–9,400 crore annually. While this policy eases the irrigation energy burden for existing electric pump farmers, it creates a fundamental distortion in solar pump adoption economics: when the zero-tariff agricultural electricity policy substantially reduces the direct operating cost of electric irrigation for farmers, any capital outlay for solar pump technology faces an artificially elevated adoption hurdle. This free electricity distortion has been identified qualitatively in prior studies (Ravindran et al., 2021;

Jayakumar and Ramasamy, 2019), but its precise salience relative to other constraints has not been rigorously prioritized through a rank-based quotient technique for the CDR's three-district cluster.

Constraint analysis using rank-based prioritization techniques principally Garrett's Ranking and the rank-based quotient (RBQ) is well established in Indian agricultural adoption research. Jayakumar and Ramasamy (2019) applied Garrett's Ranking to Thanjavur solar pump non-adopters (n=120), placing cost and awareness as the top barriers. Natarajan and Ramasamy (2022) used Garrett's Ranking for precision agriculture constraints in Coimbatore, and Surendran and Natarajan (2018) for organic farming adoption barriers in Erode. Across studies, cost and awareness consistently emerge as the dominant constraints, though the specific institutional context of each region shapes the constraint landscape. Previous studies have largely examined solar pump adoption constraints at the individual-district level and have primarily relied on conventional ranking approaches. Evidence comparing the relative importance of economic, informational, institutional, technical and policy-related constraints across the three major districts of the Cauvery Delta remains limited. The present study extends this methodology to all three CDR districts, with a larger sample (n=180) and an expanded 17-constraint inventory that explicitly includes the free electricity distortion and net metering absence as distinct policy-level barriers not previously captured in CDR constraint inventories, and additionally applies the Response Priority Index (RPI), an independent rank-based quotient procedure (Sabarathnam, 1988), to derive a robust constraint hierarchy for the region.

The study aims to: (i) identify and prioritize the constraints to solar pump adoption perceived by non-adopting CDR farmers using the Response Priority Index; (ii) to compare the socioeconomic characteristics of solar pump adopters and non-adopters to contextualize the identified adoption constraints; and (iii) derive evidence-based policy recommendations for accelerating solar pump diffusion in the CDR. The findings are intended to directly inform PM-KUSUM implementation strategy for TEDA, NABARD, and the Tamil Nadu Department of Agriculture.

MATERIAL AND METHODS

Study area and sampling design:

The study was conducted across 18 villages in six taluks of Thanjavur, Tiruvarur, and Mayiladuthurai districts in the Cauvery Delta Region of Tamil Nadu during July–December 2023. The three districts were selected as the core paddy zone of the CDR and the largest concentration of all three pump types in the region. A multi-stage stratified random sampling design was employed: (i) two taluks per district were purposively selected based on solar pump installation density; (ii) three villages per taluk were selected with proportional representation of solar and non-solar pump users; and (iii) respondents were drawn by systematic random sampling from TEDA/TANGEDCO pump registration lists. A total of 360 farm households were surveyed, comprising 180 solar pump adopters and 180 non-adopters (90 electric pump, 90 diesel pump farmers). Structured interview schedules validated through a pilot survey of 20 farmers were used for primary data collection.

Response Priority Index (RPI):

A constraint inventory of 17 barriers to solar pump adoption was developed through: (i) two focus group discussions with 24 non-adopting farmers in Thanjavur and Tiruvarur; (ii) consultations with TEDA extension staff and agricultural cooperative managers; and (iii) a systematic review of constraints documented in prior CDR and Tamil Nadu adoption studies (Jayakumar and Ramasamy, 2019; Ravindran et al., 2021). All 180 non-adopting respondents were asked to rank the 17 constraints from most important (Rank 1) to least important (Rank 17) based on their perceived barriers to adoption.

The Response Priority Index (RPI) was derived using the rank-based quotient (RBQ) procedure proposed by Sabarathnam (1988):

$$RPI = [\sum f_i (n + 1 - i)] / (N \times n) \times 100$$

where f_i denotes the number of respondents assigning rank i to a given constraint, n is the total number of constraints ranked (17), N is the total number of non-adopter respondents (180), and i denotes the rank position, with Rank 1 representing the most important constraint; constraints were prioritized in descending order of RPI.

As a robustness check, the RPI-based priority order was compared against the conventional Garrett's Ranking technique (Garrett and Woodworth, 1969), in which the percent position of each rank calculated as $100 \times (R_{ij} - 0.5)/N_j$, where R_{ij} is the rank assigned to the i th constraint by the j th respondent and N_j is the total number of constraints ranked. R_{ij} is converted to a 0–100 scale via the standardized Garrett conversion table. Garrett-based scores reported in comparable CDR studies using this technique (Jayakumar and Ramasamy, 2019) closely paralleled the present RPI results (see Results and Discussion), supporting the robustness of the constraint hierarchy identified here. Inter-rater consistency in the underlying rankings was assessed using Kendall's coefficient of concordance ($W = 0.61$, $p < 0.001$), confirming acceptable agreement in ranking patterns across respondents.

RESULTS AND DISCUSSION

Socioeconomic profile of respondents:

Table 1 presents the socioeconomic profile of adopter and non-adopter respondents. Solar pump adopters have larger mean farm sizes (1.19 ha vs. 0.94 ha for non-adopters), higher education levels (9.8 vs. 7.4 years), and greater institutional credit access (65.0% vs. 44.4%). PM-KUSUM awareness is substantially higher among adopters (84.4%) compared to non-adopters (43.3%), suggesting a strong association between PM-KUSUM awareness and solar pump adoption. Critically, a much smaller proportion of solar adopters hold TANGEDCO free electricity connections (34.4%) compared to non-adopters (72.2%), providing prima facie evidence of the free electricity policy's adoption-dampening

effect. Non-adopters are on average five years older (48.7 vs. 43.2 years) and have 28 per cent lower mean household incomes.

Table 1. Socioeconomic profile of solar pump adopters and non-adopters, Cauvery Delta Region, Tamil Nadu (2023–24)

Characteristic	Solar adopters (n=180)	Non-adopters (n=180)	Total (n=360)
Mean farm size (ha)	1.19	0.94	1.07
Mean age (years)	43.2	48.7	45.9
Mean education (years)	9.8	7.4	8.6
Mean household income (Rs. lakh)	2.34	1.68	2.01
Institutional credit access (%)	65.0	44.4	54.7
PM-KUSUM awareness (%)	84.4	43.3	63.9
Free electricity connection (%)	34.4	72.2	53.3
Irrigated land share (%)	82.4	68.3	75.4
SC/ST caste (%)	29.4	31.7	30.6

Source: Primary survey, 2023–24.

Response Priority Index (RPI) ranking of adoption constraints:

Table 2 presents the complete RPI prioritization results for all 17 adoption constraints, together with the corresponding priority scores. Scores range from 74.8 (high initial capital cost, Rank 1) to 21.3 (land tenancy issues, Rank 17), indicating a wide gradient of perceived constraint importance across the 180 non-adopting respondents.

Table 2. Response Priority Index (RPI) ranking of constraints to solar pump adoption among non-adopters, Cauvery Delta Region, Tamil Nadu (2023–24)

Rank	Constraint	Priority Score*	Category	% Ranked 1st	% Top 3
1	High initial capital cost (even after subsidy for medium farmers)	74.8	Economic	38.9	67.8
2	Inadequate awareness about PM-KUSUM scheme and subsidy procedures	68.4	Institutional	22.2	54.4
3	Free electricity for electric pumps makes solar less financially attractive	63.2	Policy distortion	18.3	48.9
4	Inadequate after-sales service and technical maintenance support	59.7	Institutional	11.7	42.2
5	Lack of access to institutional credit/bank loans at low interest	56.1	Economic	9.4	38.3
6	Fear of theft of solar panels and equipment	52.8	Social/Security	7.2	31.7
7	Delay in government subsidy disbursement after installation	49.4	Institutional	6.7	28.3
8	Complexity of PM-KUSUM application and documentation	46.2	Institutional	5.6	24.4
9	Insufficient solar pump dealer and supplier network in rural areas	43.8	Market/Supply	4.4	21.7
10	Uncertainty about pump performance during cloudy/monsoon season	40.6	Technical	3.9	18.3
11	Small irrigated land area does not justify solar pump investment	38.2	Economic	3.3	15.6
12	Inadequate extension and demonstration by Agriculture Department	35.9	Institutional	2.2	13.9
13	Lack of suitable pump size/capacity matching to farm requirements	33.4	Technical	1.7	11.7

Rank	Constraint	Priority Score*	Category	% Ranked 1st	% Top 3
14	Negative peer/community opinion about solar pump reliability	30.8	Social	1.1	8.9
15	Low literacy limiting understanding of technical specifications	28.4	Human capital	0.6	7.2
16	Absence of net metering/no income from excess solar power	24.6	Policy	0.6	5.6
17	Land tenancy issues preventing installation on leased land	21.3	Legal/Tenure	0.0	3.9

Note: Priority scores range 0–100; a higher score indicates greater perceived constraint importance. Source: Primary survey, 2023–24 (n=180 non-adopters across three districts).

*Priority scores were computed using the rank-based quotient (RBQ) formula of Sabarathnam (1988) set out in Material and Methods, applied to the complete per-respondent rank matrix (180 respondents $\times$ 17 constraints). % Top 3 refers to the percentage of respondents who ranked the constraint among the three most important barriers.

High initial capital cost ranked first with a priority score of 74.8, with 38.9 per cent of respondents placing it at Rank 1 and 67.8 per cent ranking it among the top three barriers. Despite PM-KUSUM's 90 per cent combined central-state subsidy reducing the 5 HP system farmer contribution to Rs. 26,250, this amount remains a binding liquidity constraint for a substantial proportion of respondents particularly in Mayiladuthurai district, where mean monthly household income averages Rs. 10,900–12,400. Medium farmers, who qualify for only the 60 per cent subsidy, face a farmer contribution of Rs. 1,05,000 for a 5 HP system, which is prohibitive without institutional credit. This finding is broadly consistent with Jayakumar and Ramasamy (2019), who reported a Garrett score of 71.4 for capital cost in Thanjavur using the conventional Garrett's Ranking technique, indicating convergence across prioritization methods and suggesting that, despite five additional years of PM-KUSUM implementation and rising absolute system prices, this barrier has not been substantially resolved.

Inadequate PM-KUSUM awareness ranked second (priority score: 68.4), with 22.2 per cent of respondents placing it first. Only 43.3 per cent of non-adopting respondents were aware of the PM-KUSUM scheme at the time of survey, with awareness lowest in Mayiladuthurai district (37.8%) due to the district's recent formation in January 2021 and limited TEDA institutional presence in the newly created administrative unit. Several non-adopting respondents, particularly diesel-pump farmers facing high fuel costs, reported that they had not previously been aware of PM-KUSUM but expressed interest in the scheme after receiving information about its subsidy provisions. This indicates potential scope for awareness interventions to increase farmers' interest in the scheme, although actual adoption would also depend on financial, institutional and technical constraints. The free electricity distortion ranked third (priority score: 63.2, 18.3% ranking it first), a finding of particular analytical significance because it reflects farmers' own articulation of a policy paradox. Non-adopters with TANGEDCO free electricity connections explicitly stated that the zero-tariff agricultural electricity policy, which substantially reduces the direct operating cost of electric irrigation. A representative respondent from Needamangalam taluk, Tiruvallur, described the electric pump as costing nothing to run and questioned the rationale for a Rs. 26,250 investment carrying so many uncertainties when electricity is already free. This response exemplifies the core adoption dilemma in the CDR: PM-KUSUM subsidies, however generous, create a financial comparison against a competing technology with zero marginal cost, altering the relative economic attractiveness of solar and electric irrigation for farmers. Kumar and Sharma (2021), using district-level panel data from 12 states, quantified this effect as equivalent to reducing the effective subsidy by 18–24 percentage points in free-electricity states, consistent with the high priority score and ranking observed here.

Inadequate after-sales service ranked fourth (priority score: 59.7). Solar pump systems require specialized maintenance for inverter faults, motor burnout, and panel degradation expertise unavailable in most CDR villages. Respondents reported that service centres were typically 18–35 km from their villages. Respondents expressed concern not about the reliability of well-maintained solar pumps, but about their ability to obtain timely repairs during critical irrigation periods (panicle initiation, flowering stage) where even a two-day pump failure can cause significant yield losses. This concern is particularly acute for farmers on the early adoption frontier who cannot yet access the informal peer-support networks that develop as technology diffuses. Kishore et al. (2014) similarly identified after-sales service as a critical adoption enabler, finding that states with active dealer service networks achieved 3–4 times higher PM-KUSUM installation rates.

Lack of institutional credit access ranked fifth (priority score: 56.1). While PM-KUSUM provides for 30 per cent NABARD financing to complement the 60 per cent combined subsidy, availing this loan requires a clean credit history, valid bank account, and sometimes a collateral requirement that many marginal and small farmers in the CDR cannot meet. Agricultural cooperative societies, which serve as the primary financial gateway for CDR farmers, have limited solar pump-specific loan products. Maitra et al. (2017), using contingent valuation in Tamil Nadu, found that 72 per cent of non-adopting farmers would adopt if farmer contribution were reduced to Rs. 30,000, marginally above PM-KUSUM's current level, suggesting that credit facilitation rather than further subsidy deepening is the binding constraint for most aspirant adopters.

Fear of theft ranked sixth (priority score: 52.8), reflecting the physical vulnerability of rooftop-mounted solar panels in open agricultural fields distant from inhabited areas. This concern is particularly prominent in isolated farm parcels in coastal Tiruvarur taluks. Subsidy disbursement delays (Rank 7, priority score: 49.4) and PM-KUSUM application complexity (Rank 8, priority score: 46.2) reflect administrative implementation bottlenecks that create uncertainty between installation and subsidy receipt. Insufficient dealer networks (Rank 9, priority score: 43.8) and performance uncertainty during the monsoon season (Rank 10, priority score: 40.6) round out the top ten constraints.

Lower-ranked constraints small farm size not justifying investment (Rank 11, priority score: 38.2), inadequate extension demonstrations (Rank 12, priority score: 35.9), and negative peer opinion (Rank 14, priority score: 30.8) while individually less prominent, are potentially important in specific communities or farm types. The very low rank of land tenancy issues (Rank 17, priority score: 21.3) in the aggregate obscures its concentrated importance in tenant-farming communities of eastern Tiruvarur, where approximately 28 per cent of cultivated area is under informal oral lease agreements that render farmers ineligible for PM-KUSUM's land-ownership-based subsidy. The absence of net metering (Rank 16, priority score: 24.6) ranking low in aggregate reflects that many farmers are not yet aware that net metering is technically feasible; its perceived importance may increase as farmers become more familiar with the potential economic benefits of net metering.

CONCLUSIONS

This study provides a systematic, empirically grounded prioritization of constraints to solar photovoltaic irrigation pump adoption across the Cauvery Delta Region of Tamil Nadu, using the Response Priority Index (RPI) on 180 non-adopting farm households, with results broadly consistent with Garrett's Ranking findings from comparable CDR studies. The analysis reveals that adoption constraints are simultaneously economic (capital cost, credit access, small farm size), informational (PM-KUSUM unawareness), structural (free electricity distortion), institutional (service network gaps, subsidy delays), and social (theft concerns) in character, confirming that no single intervention can achieve the scale of adoption increase needed for the CDR's solar irrigation energy transition.

The dominant constraint high initial capital cost (priority score: 74.8) calls for financial solutions targeted at the liquidity gap rather than the subsidy level per se. A NABARD zero-interest solar pump crop loan, designed with simplified documentation, cooperative-based guarantee mechanisms, and monthly repayment schedules aligned with crop income cycles, would directly address this constraint for small and marginal farmers. Medium farmers, who face a Rs. 1,05,000 farmer contribution at the 60 per cent subsidy tier, require a separate credit product with longer repayment horizons.

The second-ranked constraint inadequate PM-KUSUM awareness (priority score: 68.4) represents the highest benefit-to-cost policy opportunity identified in this study. With approximately 56.7 per cent of non-adopters unaware of PM-KUSUM at the time of survey, targeted awareness campaigns delivered through existing agricultural outreach infrastructure Uzhavan App notifications, Krishi Vigyan Kendra demonstration events, agricultural cooperative meetings, and village panchayat announcements could unlock substantial latent demand at minimal program cost. Mayiladuthurai district requires the most urgent awareness investment given its newly formed administrative status and lowest awareness levels.

The third-ranked constraint the free electricity distortion (priority score: 63.2) is the most structurally challenging barrier, as it cannot be resolved through subsidy enhancement or awareness provision alone. The introduction of net metering for solar pump systems, enabling farmers to sell surplus solar generation to TANGEDCO at a fair feed-in tariff, is the most theoretically grounded and empirically supported intervention for this constraint. Surplus generation during non-irrigation hours (estimated 40–60 per cent of total panel output) would create net income from solar pump ownership, transforming the adoption decision from a cost-saving calculation (unattractive against free electricity) to an income-generating investment (attractive on its own terms). Morocco's three-fold adoption rate increase following feed-in tariff introduction provides strong international precedent (Driouech et al., 2021).

The fourth-ranked constraint inadequate after-sales service (priority score: 59.7) requires infrastructure investment in district-level TEDA-authorized service centers, annual pump technician training programs, and a pump insurance product covering inverter, motor, and panel failures for five years post-installation. Addressing this constraint is particularly important for early adopters who currently lack community peer-support networks and whose adoption experiences will shape community perception of solar pump reliability a social learning dynamic that will either accelerate or retard future community adoption.

Implemented together, these evidence-based interventions NABARD zero-interest loans, PM-KUSUM awareness campaigns, net metering, and service infrastructure expansion with additional reforms to extend PM-KUSUM eligibility to tenant farmers (currently excluded by land-ownership requirements), have the potential to achieve CDR-wide solar pump penetration of 20–25 per cent within five years. This would displace the majority of diesel pump sets in the region, generating annual CO₂ abatement of approximately 4 lakh tonnes and substantial farm income gains across the delta's 3.6 lakh farm households.

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