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Training Manual

Technical and Financial Aspects of Solar Irrigation Pumps in India

(Under Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan Yojana)

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About Solar Energy for Agricultural Resilience (SoLAR)

International Water Management Institute (IWMI) has launched the second phase of the Solar Energy for Agricultural Resilience (SoLAR) project, supported by the Swiss Agency for Development and Cooperation (SDC). Running from July 2025 to December 2029, this new phase expands both the geographical and thematic scope of the initiative to strengthen climate resilience and drive agricultural transformation through solar energy. Building on the achievements and lessons of Phase 1 (December 2019 – May 2024) across Bangladesh, India, Nepal, and Pakistan, Phase 2 extends the project's reach to Ethiopia and Kenya, while scaling up interventions in Bangladesh and India. Through South–South collaboration, SoLAR aims to establish solar-powered agricultural systems as a replicable and scalable model for sustainable, socially inclusive, and climate-resilient agriculture across the Global South.

About CGIAR Scaling for Impact Program

CGIAR's Scaling for Impact Program tackles global poverty, food insecurity, and climate risks by applying transdisciplinary science, fostering partnerships, generating evidence, and delivering integrated solutions to maximize impact and minimize duplication in Bangladesh, Benin, Cambodia, Colombia, Côte d'Ivoire, Democratic Republic of the Congo, Egypt, Ethiopia, Guatemala, Honduras, India, Indonesia, Kenya, Malawi, Mexico, Morocco, Myanmar, Nepal, Nigeria, Pakistan, Peru, Philippines, Senegal, Sri Lanka, Sudan, Tanzania, Tunisia, Uganda, Uzbekistan, Vietnam, Zambia, Zimbabwe.

Organisations

International Water Management Institute (IWMI)

The International Water Management Institute (IWMI) is an international, research-for-development organisation, with offices in 17 countries and a global network of scientists operating in more than 55 countries. For over three decades, our research results have led to changes in water management that have contributed to social and economic development. IWMI's vision is that of a water-secure world. IWMI targets water and land management challenges faced by poor communities in developing countries, and through this, it contributes towards the achievement of the Sustainable Development Goals (SDGs) of reducing poverty and hunger and maintaining a sustainable environment. Based on evidence and knowledge drawn from science, innovative technologies, and the testing of business models, IWMI works with governments, policymakers, farmers, civil society, water managers, development partners, and businesses to solve water problems and scale up solutions. Through partnerships, IWMI combines research on the sustainable use of water and land resources, knowledge services, and products with capacity strengthening, dialogue, and policy analysis to support the implementation of water management solutions for agriculture, ecosystems, climate change, and inclusive economic growth.

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Disclaimer

Preface

The Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan (PM-KUSUM) is a flagship initiative of the Government of India to promote solar energy in agriculture, reduce dependence on fossil fuels, and enhance farmer livelihoods. As part of India's Nationally Determined Contributions (NDCs), the scheme supports the target of achieving 40% of installed power capacity from non-fossil sources by 2030. By March 2026, PM-KUSUM aims to add 34,800 MW of solar capacity with a Central Financial support of $3.63 billion USD, including service charges for implementing agencies.

This training manual focuses on Component B (Off-Grid Solar Irrigation Pumps, SIPs) and Component C1 (Grid-connected individual SIPs). Field experiences show that long-term success of these schemes depends on farmer awareness, training, and confidence in using solar technology. Key barriers include limited awareness of scheme provisions, its application/benefits to their livelihoods, uncertainty about technical performance, low familiarity with financial procedures, and hesitation in adopting new technology in general, e.g. its application/benefits to their households and livelihoods. Farmers need guidance and support on technical and financial aspects- cost and benefits of solar irrigation, awareness on PM KUSUM, basic operation and maintenance, etc. This manual addresses these barriers by strengthening the capacities of local stakeholders who engage with farmers on a regular basis.

Against this backdrop, the manual has been developed as a practical resource for agriculture extension agents or other stakeholders who interact with farmers on a regular basis. Its objective is to equip facilitators with clear, field-oriented guidance to support the adoption, operation, and maintenance of solar irrigation systems. The manual combines technical explanations, farmer-friendly tools, and case-based examples to promote interactive and effective training at the grassroots level.

By addressing both technical and financial knowledge gaps, the manual aims to ensure that farmers—especially smallholders and women farmers—can maximise the benefits of solar irrigation. In doing so, it seeks to strengthen the capacity of extension agents, enhance adoption rates, and embed solar irrigation as a cornerstone of sustainable and resilient agriculture.

This training manual is not a standalone product. It has been developed as part of a broader study under the SoLAR project on institutionalising Energy Extension Agents and Citizen Service Centres to scale solar irrigation in India. The study will be piloted in 96 villages using a randomized controlled trial (RCT) framework, where trained agricultural extension agents will conduct outreach activities and raise awareness about SIPs and PM-KUSUM through one-on-one interactions with 1,280 farmers across 64 villages.

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Abbreviations

AC	**Alternating Current**
CFA	Central Financial Assistance
CO_2	Carbon Dioxide
CSR	Corporate Social Responsibility
DC	Direct Current
DISCOM	Distribution Companies
EESL	Energy Efficiency Services Ltd.
FLS	Feeder-Level Solarisation
FPO	Farmer Producer Organisations
HP	Horsepower
IPS	Individual Pump Solarisation
KCC	Kisan Credit Card
KVK	Krishi Vigyan Kendras
kWh	Kilowatt-hour
MNRE	Ministry of New and Renewable Energy
MPPT	Maximum Power Point Tracker
MW	Megawatt
NDC	Nationally Determined Contributions
O&M	Operation & Maintenance
OTP	One Time Password
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
PPA	Power Purchase Agreement
PV	Photovoltaic
SHG	Self-help group
SIP	Solar Irrigation Pump
SNA	State Nodal Agency
TDH	Total Dynamic Head
UP	Uttar Pradesh
UPNEDA	Uttar Pradesh New and Renewable Energy Development Agency
WUA	Water User Associations

Sustainable Farming through Solar Irrigation Pumps

1. Introduction to Solar Irrigation Pumps (SIPs)

1.1 Background

Agriculture is the backbone of many developing economies, including India. To improve farm productivity and farmer incomes, irrigation must be both reliable and affordable. But irrigation also depends on energy, creating a close link between water, energy, and food—known as the water-energy-food (WEF) nexus. The WEF nexus highlights how these three systems depend on one another. These interactions can create a reinforcing cycle of groundwater overextraction, rising energy use, and increasing emissions (see Figure 1).

In India, irrigation has mostly relied on pumps powered by either grid electricity or diesel. Grid supply in rural areas is often unreliable or unavailable, while diesel pumps are costly to run and cause pollution. In response, renewable energy in agriculture is increasingly being promoted as a more sustainable option. Among these, Solar Irrigation Pumps (SIPs) have become especially important, as they provide farmers with clean, dependable, and cost-effective power for irrigation.

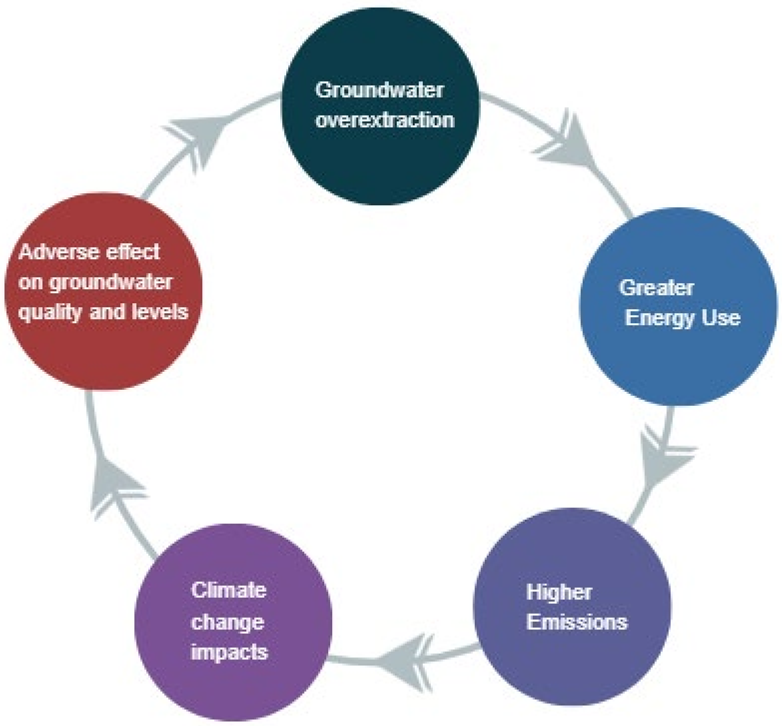

Figure 1. The Vicious Cycle of Irrigation
Source: Authors' conceptualisation

Most irrigation pumps in India run on fossil fuels. About 76% are electric, 22% are diesel, and only 2% use renewable energy. Out of nearly 30 million (3 crore) agricultural pumps, around 8 million (80 lakh) are diesel operated. Diesel pumps consume approximately 5.52 billion litres of fuel annually, resulting in an estimated 15.4 million tonnes of CO_2 emissions (MNRE, 2019). Since most electricity in India is still generated from coal and other fossil fuels, grid-powered electric pumps also contribute substantially to carbon emissions.

Groundwater irrigation overall emits 45–62 million metric tonnes of Carbon annually, equivalent to about 8–11% of India's total carbon emissions. Within this, electric pumps account for 43–57.5 million metric tons of Carbon, while diesel pumps add 3.2–4.8 million metric tons of Carbon.

High carbon emissions and groundwater overuse adversely affect farming, increasing costs and reducing yields at the farm level, while depleting aquifers, straining the power sector, and threatening national food security.

1.2 What are the Benefits of Solar Irrigation Pumps?

Beyond providing clean and reliable energy for irrigation, SIPs deliver a wide range of technology, economic, environmental, and social benefits that strengthen farm livelihoods and promote sustainable agriculture.

A. Technology and Economic Benefits

a. Clean and renewable: Runs on solar energy, reducing dependence on diesel and grid electricity.
b. Low maintenance: Simple design with fewer parts reduces servicing needs compared to diesel pumps.
c. Reliable supply: Provides assured day-time irrigation even in remote areas with poor grid connectivity.

B. Economic Benefits

a. Cost-saving: No fuel expenses and lower operation and maintenance costs, leading to higher farm income.
b. Better productivity and Increased farm income: Timely irrigation supports multiple crops and high-value farming.
c. Income from electricity: Surplus energy can be sold to the grid (where feasible), generating an additional revenue stream.
d. Diversified livelihoods: Extra solar power can be used for other farm-related activities, such as rice milling or small agro-processing, further boosting income.
e. Faster payback: Savings on diesel and extra income from crops/energy help recover the initial investment in a short period.

C. **Environmental and Social Benefits**

a. Climate-friendly: Reduction in greenhouse gas emissions, helping to reduce climate change impacts.
b. Cleaner and quieter villages: No smoke, noise, or local pollution from diesel pumps.
c. Women-friendly technology: Reduce drudgery, lower operating costs, and strengthen women farmers' control over irrigation and farm decisions.
d. Supports water sustainability: When combined with drip or sprinkler systems, SIPs help conserve groundwater. Additionally, the economic incentives also matter for improving irrigation efficiency.

1.3 Case Examples/Success Stories

Real-world experiences show how solar irrigation pumps (SIPs) deliver both economic and environmental benefits for farmers. Two examples from Rajasthan and Gujarat highlight different pathways to success.

(A) Rajasthan

Higher Profits from Solar vs. Diesel Pumps in Rajasthan, studies comparing solar and diesel pumps for crops like groundnut and pearl millet showed significant economic gains:

- Farmers using solar pumps earned on average ₹30,000 more per crop season than diesel pump users.
- Solar eliminated fuel costs, cutting irrigation expenses sharply.
- Investments paid back quickly due to savings on diesel. The experience from Rajasthan showed that farmers saved INR 11000 annually on diesel after adopting SIPs.
- The benefit–cost ratio of solar pumps was 3 to 4 times higher than diesel pumps.

How Solar Brings Change: Switching from diesel → Lower irrigation cost → Faster payback → Higher farmer income.

(B) Dhundi Village, Gujarat – A Cooperative Solar Model

In 2015, IWMI pioneered a farmer-owned cooperative called SPICE (Solar Pump Irrigators' Cooperative Enterprise) in Dhundi village:

- Farmers received grid-connected solar pumps, enabling them to irrigate fields and sell surplus electricity back to the grid through Madhya Gujarat Vij Company Ltd. (MGVCL).
- This created a new income stream—treating solar energy like a "cash crop" with almost no input costs.
- The success led to the Suryashakthi Kisan Yojna (SKY) and Grid-connected component of PM-KUSUM.
- Farmers reduced groundwater pumping, used energy more sustainably, and improved climate resilience.

How Solar Brings Change: Solar → Income diversification & sustainability → Behavioural shift → Eco-friendly farming. Table 1 provides a comparative assessment of solar, diesel, and electric irrigation pumps across cost structures, environmental impacts, and operational suitability, highlighting the long-term economic and sustainability advantages of solar irrigation systems.

Table 1. Comparison of Solar, Diesel, and Electric Irrigation Pumps

Criteria	Solar Irrigation Pumps (SIPs)	Diesel Pumps	Electric Pumps
Power source	Solar	Diesel (fossil fuel)	Grid electricity (mix of fossil and non-fossil fuels)
Operating Cost	*Zero fuel cost (~$2,650 saved, on 5HP pumps in just 10 years)*	High recurring fuel cost *Diesel rental: ~$2.4/acre/hr → ~$72–96/acre/season*	Moderate or low—depends on tariff and hours used; generally cheaper than diesel
Maintenance	Low (few moving parts)	High (engine wear and fuel system issues)	Medium
Environmental Impact	Zero emissions	High CO_2 and particulate emissions	Indirect emissions (if grid uses coal)

Suitability in Remote Areas	Excellent	Good	Limited (depends on grid access)
Initial Cost	High (but heavily subsidised) *2025 cost for 3–5 HP: ~$2,290–3,490 [Government is giving subsidies in range of 60%-90%]*	Low to medium *One-acre diesel irrigation fuel subsidy in Bihar~$9 per irrigation at ~$0.90/L diesel*	Medium (depends on motor and installation)- *From Telangana project cost: ~$/year electricity ~$560 per acre electricity annually*
Dependence on External Supply	None	High (fuel supply)	High (electricity availability)
Noise Pollution	None	Significant	Low
Long-Term Economic Viability	High (minimal running cost + subsidies)	Low (costly fuel over time)	Medium (operating costs vary with tariff and usage)

Source: Author’s assumptions based on research studies.

Understanding the PM KUSUM Scheme

2. Understanding the PM-KUSUM Scheme

2.1 Introduction

The Pradhan Mantri Kisan Urja Suraksha Evam Utthan Mahabhiyan (PM-KUSUM) launched in 2019 is a flagship initiative of the Government of India aimed at promoting solar energy in agriculture, reducing dependence on fossil fuels, and enhancing farmer livelihoods. As part of India's Nationally Determined Contributions (NDCs), the scheme supports the target of achieving 40% of installed power capacity from non-fossil sources by 2030. By March 2026, PM-KUSUM aims to add 34,800 MW of solar capacity with a Central Financial support of ₹34,422 crore, including service charges for implementing agencies.

Key Components of PM-KUSUM

The scheme is structured around three main components (see Figure 2), each addressing different aspects of renewable energy adoption in agriculture, with key guidelines presented in Table 2..

The Scheme has the following three components:

- Component-A: Setting up of 10,000 MW of Decentralized Ground/ Stilt Mounted Grid-Connected Solar or other Renewable Energy based Power Plants.
- Component-B: Installation of 14 Lakh Stand-alone Solar Agriculture Pumps.
- Component-C: Solarisation of 35 Lakh Grid Connected Agriculture Pumps including Feeder Level Solarization.

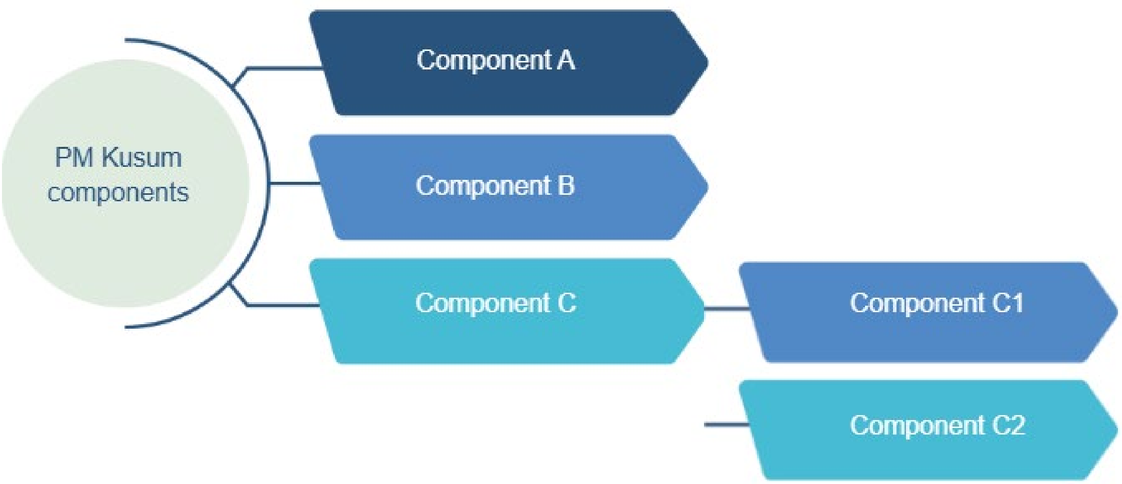

Figure 2. PM KUSUM Components

Note: This training manual focuses on PM KUSUM Components B and C1, providing guidance on their implementation, operation, and key technical aspects.

General Guidelines of PM-KUSUM by Ministry of New and Renewable Energy, Government of India (All-India Level)

Table 2. Guidelines on PM-KUSUM by MNRE

Component B – Standalone Solar Pumps (up to 7.5 HP), focus of this training module
• For off-grid areas.
• Central Financial Assistance (CFA): 30% (50% in NE states, hilly UTs, islands).
• States provide ≥30% subsidy; farmer contributes 40% (reduced to 20% in special states/UTs).
• Bank loan option: farmer pays only 10% upfront.
• Central CFA available even if state share not provided.
Component C1 – Individual Pump Solarisation (IPS), focus of this training module
• Grid-connected pumps solarised; PV up to 2× pump capacity.
• Farmers use solar for irrigation; sell surplus to DISCOMs.
• CFA: 30% (50% in NE states, hilly UTs, islands).
• State subsidy ≥30%, farmer max 40% (reduced to 20% in special states/UTs).
• Loan option: 10% upfront, rest as loan.
• Central CFA allowed even without state share.
Component C2 – Feeder Level Solarisation (FLS)
• States can solarise entire agri-feeders (guidelines issued Dec 2020).
• Loan for feeder separation via NABARD/PFC/REC; RDSS support available.
• Solar plants installed via CAPEX/RESCO for 25 years.
• CFA: 30% (₹1.05 Cr/MW cap) or 50% in NE/hilly UTs/islands (₹1.75 Cr/MW cap).
• Farmers receive reliable daytime power free or at state tariff.

Some Conditions for Water-Stressed (Dark/Black) Zones

I. Only the existing diesel pumps can be replaced with solar pumps under Component-B and existing electric pumps can be solarised under Component-C in these areas provided they use micro-irrigation techniques to save water.
II. Farmers who use micro-irrigation systems or plan to adopt them are given priority for installing standalone solar pumps or solarising their existing pumps.
III. The size of the solar pump depends on the local water table, farm area, and water needs.
IV. Farmers with grid-connected solar pumps can sell any extra electricity to the DISCOM and earn additional income.
V. For feeder-level solarisation, farmers are rewarded if they use less electricity than the set benchmark, encouraging efficient water and energy use.

State-Specific Guidelines for PM-KUSUM B and C1: Uttar Pradesh

The implementing agency for PM-KUSUM B and C1 are:

I. Component C1, Individual Pump Solarisation (IPS): Uttar Pradesh New and Renewable Energy Development Agency (UPNEDA), Government of Uttar Pradesh
II. Component B – Standalone Solar Pumps (up to 7.5 HP): Department of Agriculture and Farmers' Welfare, Government of Uttar Pradesh

Component B – Standalone Solar Pumps (up to 7.5 HP)

PM KUSUM Component B focuses on installing standalone solar-powered pumps to support off-grid irrigation for farmers. It promotes the adoption of clean energy while reducing dependence on diesel and grid electricity. See Figure 3, which illustrates the system's basic structure and functionality.

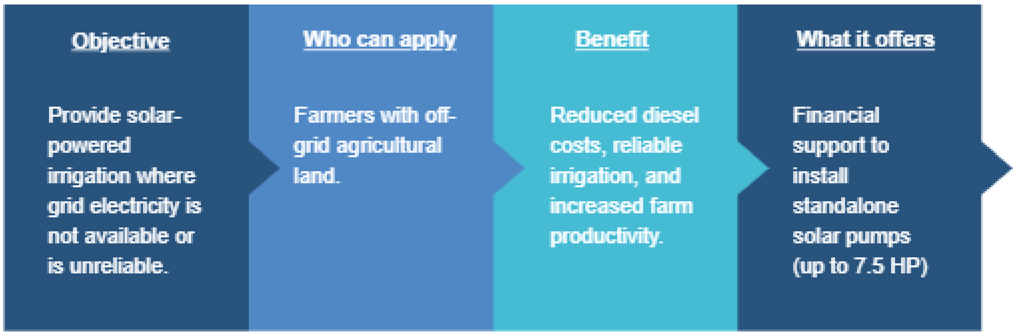

Figure 3. Schematic of PM KUSUM component B

Current Progress in PM-KUSUM Component B in Uttar Pradesh

- Installed Pumps: As of September 2025, approximately **66,498** pumps have been installed.

Component C1 – Individual Pump Solarisation (IPS)

- Existing grid-connected agricultural pumps are retrofitted with solar panels.
- Solar energy powers the pump during the day, and surplus power can be exported to the grid.
- Farmers receive monetary compensation for surplus energy, making them energy producers (See figure 4).
- **System: Solar + Grid Hybrid Pump:**
  - Solar-generated power is first used; grid electricity is used as a backup.
  - Extra solar electricity can be exported to the grid for income.

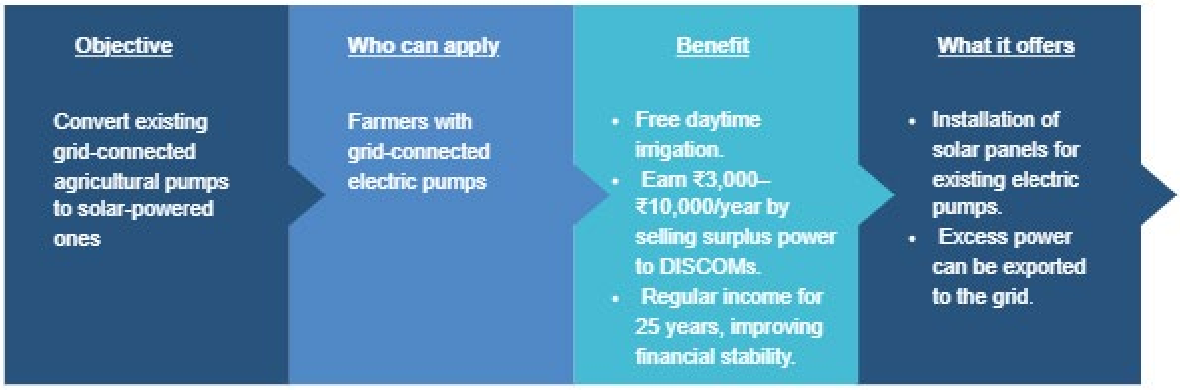

Figure 4. Schematic of PM KUSUM component C1

Current Progress in PM-KUSUM Component C1

- As of December 2025, only 4771 electric pumps have been solarised so far.

Relevance of Component C1 (Individual Pump Solarisation)

- Empowers farmers to become prosumers (producers + consumers) of energy.
- Helps reduce subsidy burden on discoms.
- Encourages efficient electricity use and provides an additional source of income to farmers.

Design Criteria:

- Pumps above 7.5 HP can be solarised, but subsidy is limited to 7.5 HP.
- Solar panels up to 2x pump capacity allowed. Surplus power can be sold to DISCOMs through net metering.

2.2. Subsidies and Financial Assistance for Farmers in Uttar Pradesh

<u>**For Component B in Uttar Pradesh:**</u>

- **State Government Subsidy**: ***60%** subsidy for farmers (See figure 5 for a more detailed Breakup).

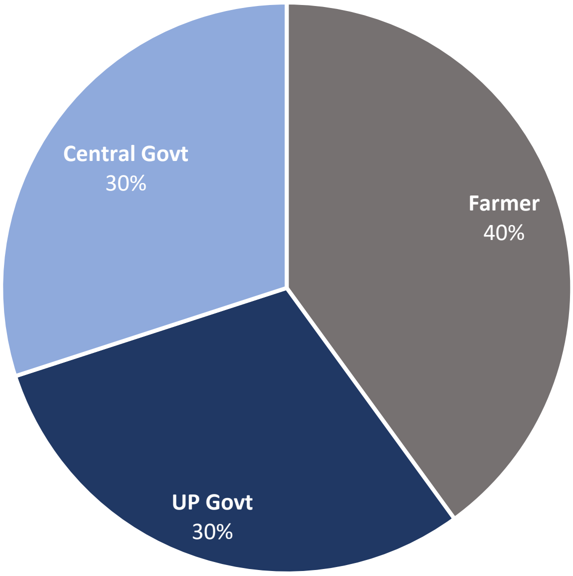

Figure 5. Subsidy structure of PM-KUSUM component B

  - <u>**Implementing agency**</u>: **Department of Agriculture and Farmers' Welfare, Uttar Pradesh**

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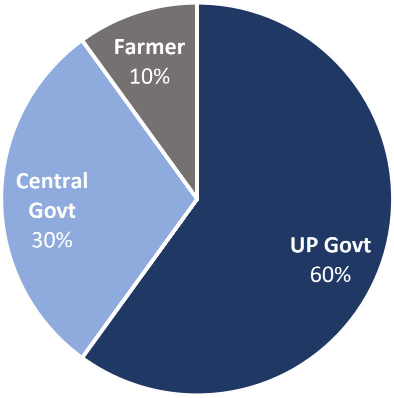
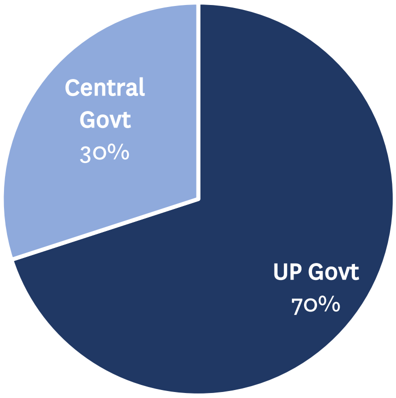
For Component C1 in Uttar Pradesh:

- **State Government Subsidy**: (see Figure 6-A for distribution)**90%** for general category farmers, and (see Figure 6-B for distribution) **100%** subsidy for Scheduled Tribe, Vantangia and Musahar caste farmers.



(A)



(B)

Figure 6. Subsidy structure of PM-KUSUM component C1-(A)General category farmers; (B) Scheduled Tribe, Vantangia and Musahar caste farmers.

Features:

- **Solar capacity:** Allows installation of a solar PV capacity up to ***two times of pump capacity in kW.***
- **Eligibility:** Individual farmers, Water User Associations (WUA), and community/cluster-based irrigation system are eligible under this scheme.
- **Surplus power:** The installation generated solar power can be used to meet the irrigation needs, while the excess power can be sold to DISCOMs at pre-fixed tariff typically ranging between Rs 2 to Rs 3.00 per kWh thereby creating a means for farmers to enhance income generation.
- **Subsidy:** Limited to **7.5 HP.** Higher capacity pumps allowed with limit of subsidy up to 7.5 HP only.

Net Metering Support

- Net-metering (see Figure 7) is like a give-and-take system between the electricity-consumer and the DISCOM.
    - Farmers with solarised grid-connected pumps can generate electricity more than the electricity required for irrigation.
    - This surplus electricity is sold to the grid *(the DISCOM)* at a pre-determined tariff.
    - The meter keeps track, and this supplied surplus power is stored as *credits.*
    - Later, when the solar panels aren't producing enough (like at night or cloudy days), these credits help offset the cost of electricity drawn from the grid.
    - At the end of the billing period, the utility *(DISCOM)* calculates the "net" amount of electricity consumed from the grid and subtracts the value of the credits, resulting in a lower bill.

How Component C1 Operates in Uttar Pradesh

Key Difference from Gujarat

- In UP, **farmers can only export surplus electricity to the grid when grid electricity is available in the village**.
    - This means: If the grid isn't supplying power (e.g., during outages), solar-generated electricity must be used on the farm-even if there's surplus.
    - Only when the grid is live does the net metering system allow surplus solar energy to be exported and compensated (refer to Figure 7 which shows the operational mechanism of Net-Metering).

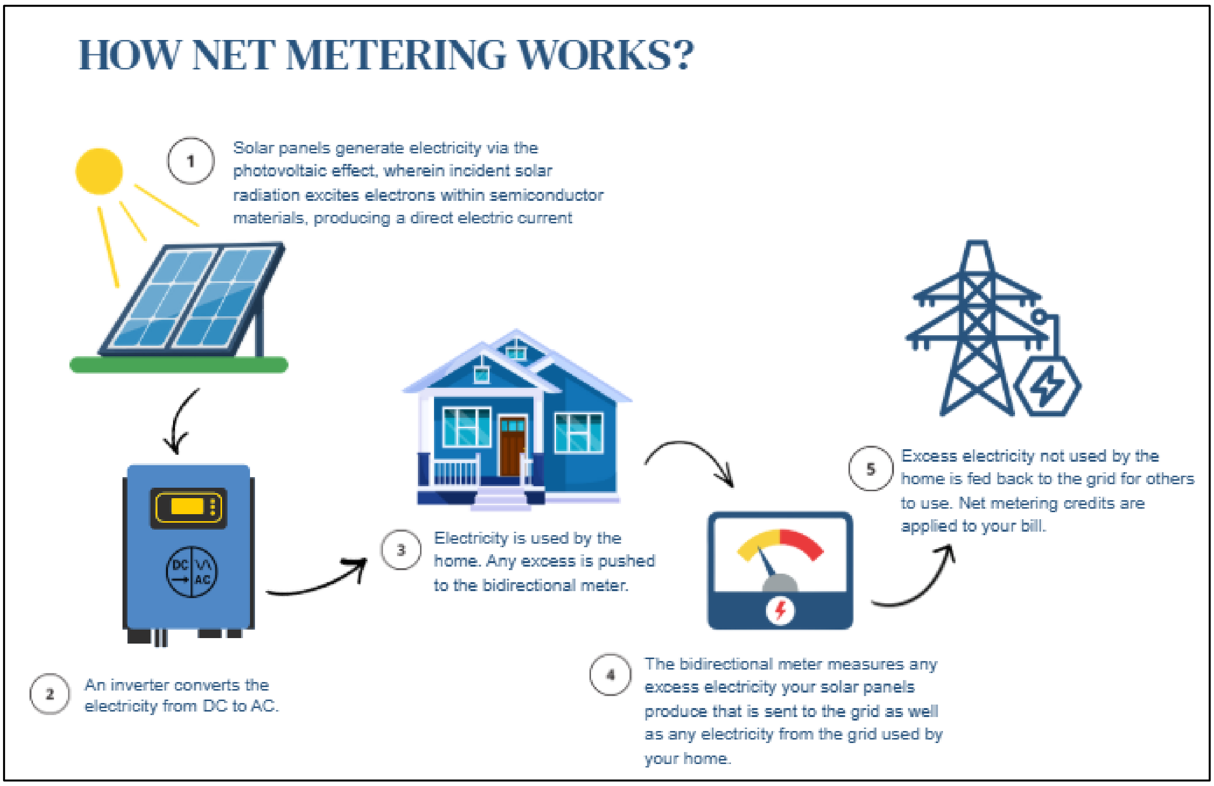


Figure 7. A schematic illustrating energy flow in a rooftop solar net-metering system.

Why this difference matters

- **Gujarat:** Farmers can keep exporting solar power all day, as long as their system is connected. This makes solarisation an **income-oriented model** (extra earnings from selling surplus power).
- **Uttar Pradesh:** Farmers can **only export when the feeder is live**.

This ensures:

1. **Irrigation first** - Solar power is mainly used to run the pump.
2. **Less dependence on the grid** - Even if the grid is off, the pump can still run on solar, so farmers are not left without water.
3. **But export income is limited** - because grid supply hours are restricted.

Therefore,

- Gujarat prioritises making solar a "second crop" (steady income).
- UP prioritises **water security** (solar for irrigation first), while only allowing exports when the grid is active.

Technical Aspects of Solar Irrigation Pump Installation and Operation

3. Technical Aspects of SIP Installation and Operation

3.1 Basic Functioning and Components of Solar Irrigation Pumps

A Solar Irrigation Pump converts solar energy into electrical energy to draw water from a source (such as a borewell, pond, or river) for irrigation purposes. The system operates using photovoltaic panels that generate direct current, which powers the motor attached to a water pump. The various components of the solar irrigation setup are listed in Table 3.

Table 3. Core Components of SIPs

Component	Function
Solar PV Panels	Convert sunlight into DC electricity
Mounting Structure	Holds panels at the correct tilt and orientation to maximise solar exposure
Pump Controller/Inverter	Regulates power flow; converts DC to AC if needed
Electric Motor	Converts electrical energy into mechanical energy
Water Pump	Lifts or draws water for irrigation (surface or submersible)
Storage or Distribution System	Tanks or piping for storing and distributing water

3.1.2 Pump Types

- **DC Pumps**: Operate directly on solar-generated DC power. Simple and efficient for small-scale applications.
- **AC Pumps**: Require an inverter to convert DC to AC. Suitable for higher loads or retrofitting existing AC pumps.

3.1.3 Pump Configurations

- **Surface Pumps**: Ideal when the water source is less than 7–9 meters deep.
- **Submersible Pumps**: Used when the water table is deeper (up to 100 meters or more).

Balance of system (BOS) of Solar Pump System

The balance of system (BOS) of a solar pump system, as illustrated in Figure 8, comprises the supporting infrastructure and electrical components that enable efficient and safe operation of solar energy generation and utilization. The system begins with the foundation and module mounting structure, which provide stability and ensure optimal orientation of PV modules for maximum solar exposure. The PV modules generate direct current (DC) electricity, which is transmitted through DC cables to the DC junction box for aggregation and protection before being converted into alternating current (AC) by the grid-tie inverter. The AC power is then routed via AC cables to the AC junction box for distribution, with energy flows monitored through generation and net meters. Additional components such as communication cables enable remote monitoring, while earth pits and lightning arrestors ensure system safety by providing grounding and protection against electrical surges.

Collectively, these BOS components are critical for maintaining system reliability, performance, and integration with the grid. See table 4 for the detailed description of individual components.

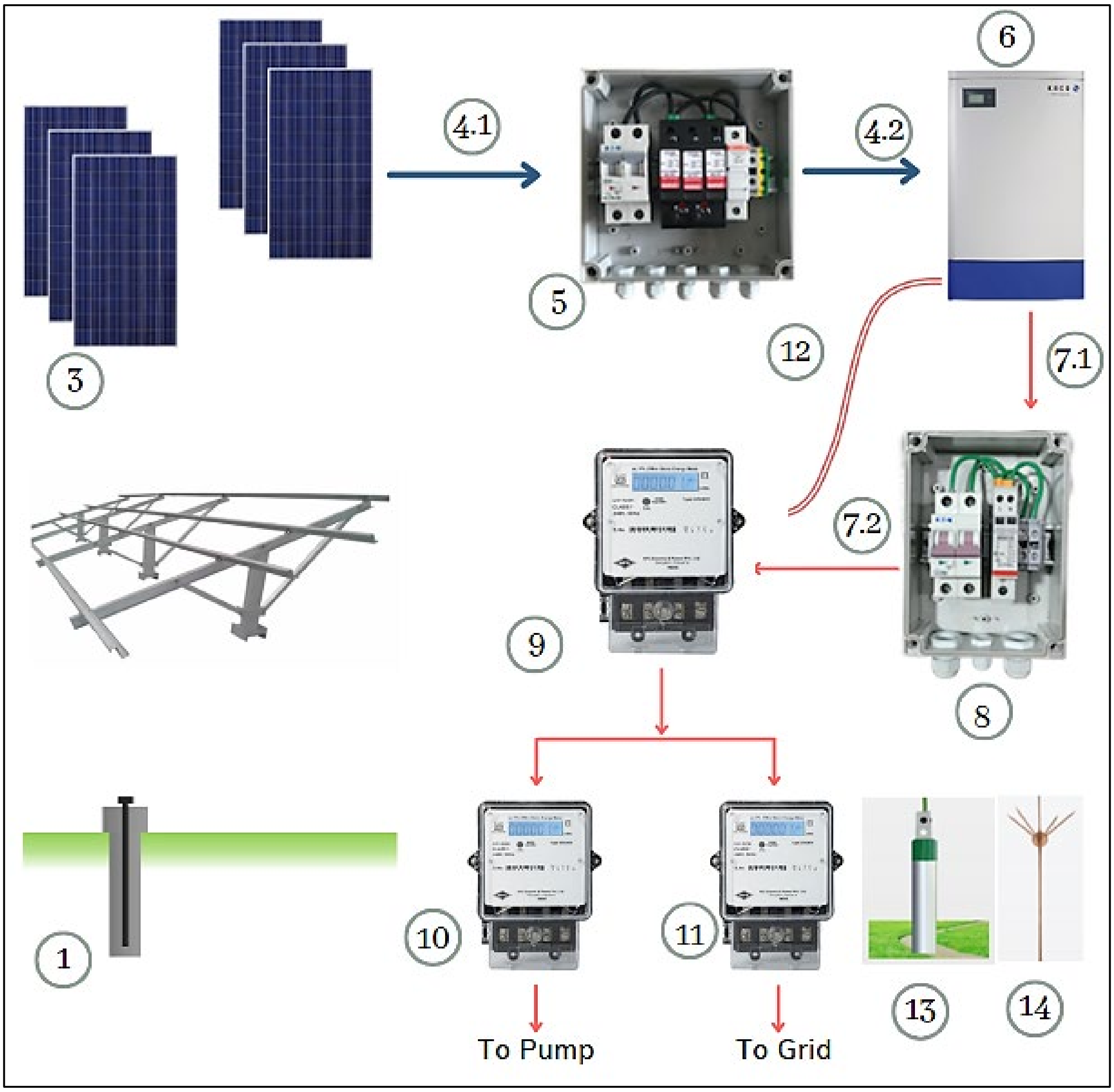


Figure 8. BOS of Solar Pump System 1. Foundation; 2. Module Mounting Structure;3. PV Modules;4. DC Cables (4.1 and 4.2); 5. DC Junction Box; 6. Grid-tie Inverter;7. AC Cable (7.1 and 7.2) ; 8. AC Junction Box;9. Generation Meter;10. Consumption Meter;11. Net Meter;12. Communication Cable;13. Earth Pits;14. Lightening Arrestor
Source: GERMI

Table 4. Balance of System (BoS) Components in a Solar Irrigation Pump System with Functional Descriptions

Foundation Provides a stable and secure base for mounting the solar structure.	**Module Mounting Structure** Holds the PV modules at the correct angle for optimal sunlight exposure.
PV Modules Convert sunlight into direct current (DC) electricity.	**DC Cables (4.1 & 4.2)** Carry DC electricity from the solar panels to the inverter and junction box.

DC Junction Box Combines power from multiple panel strings and offers protective functions.	**Grid-tie Inverter** Converts DC power from panels into AC suitable for grid use.
AC Cables (7.1 & 7.2) Carry AC power from the inverter to the load or the utility grid.	**AC Junction Box** Distributes AC power and houses safety devices such as circuit breakers.
Generation Meter Records the total solar energy generated by the system.	**Net Meter** Calculates net electricity used by subtracting solar generation from grid consumption.
Communication Cable Connects system components for remote monitoring and control.	**Earth Pits** Provide proper grounding to ensure safety from electrical faults.
Lightning Arrestor Protects the system from voltage surges due to lightning strikes.	

3.2 Installation Requirements and Site Selection

Successful deployment of SIPs depends on proper site assessment, design optimisation, and correct installation procedures.

3.2.1 Site Selection Criteria

- **Solar Access**: Unshaded area with high solar irradiance (preferably >4.5 kWh/m²/day).
- **Orientation and Tilt**: Generally, south-facing in India, with tilt angle approximately equal to the site's latitude.
- **Water Source Proximity**: Borewell, pond, canal, or river should be within efficient pumping range.
- **Land Availability**: For panel installation—usually requires 10 m²/kW for fixed mounts.
- **Soil Type**: Stable ground to anchor mounting structures; avoid loose or waterlogged soils.

3.2.2 Installation Guidelines

- **Structural Foundations**: Mounting structures must be anchored using concrete pedestals or metal poles.
- **Cable Layout**: Should follow proper conduit routing to avoid physical damage and minimise power loss.
- **Earthing and Lightning Protection**: To protect against surges and ensure system safety.
- **Pump Depth and Sizing**: Based on Total Dynamic Head (TDH), discharge requirements, and solar availability.

3.2.3 Safety Considerations

- Use certified components (as per MNRE/BIS standards).
- Implement signage, fencing, and safe distance protocols.
- Follow electrical safety norms (IS 732 and IS 3043).

PV MODULES

PV modules are made of semiconductor material silicon, which converts the light component of sunlight directly into DC electricity. Polycrystalline PV modules are used in the SKY scheme (see Figure 9 for different types of PV modules).

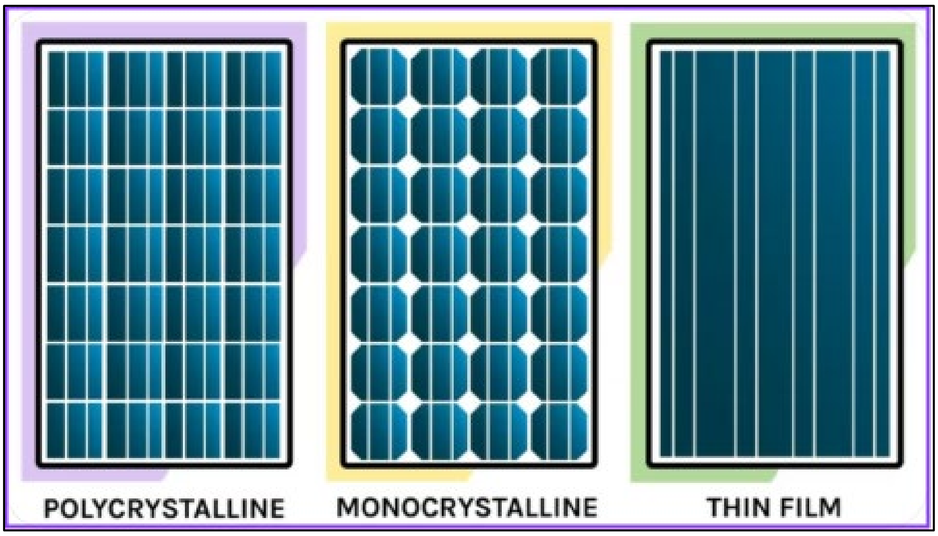


Figure 9. Different types of PV modules (*Source:* GERMI)

PV modules are rated for a specific peak power (e.g., 320-Watt Peak). The module specifications are provided by the manufacturer on a nameplate given behind the module, as shown in the Figure 10 and 11.

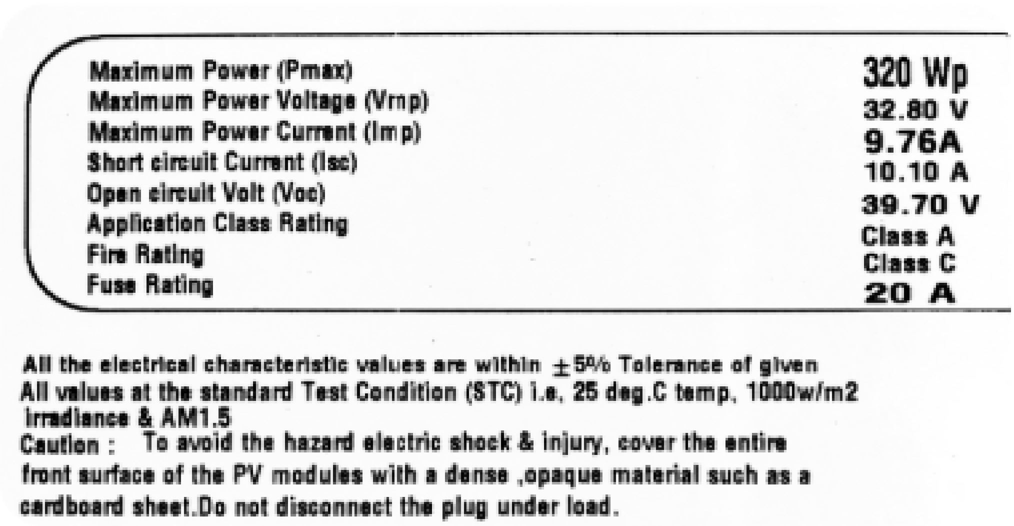


Figure 10. Sample snippet of a rating and wattage of a PV module (*Source:* GERMI)

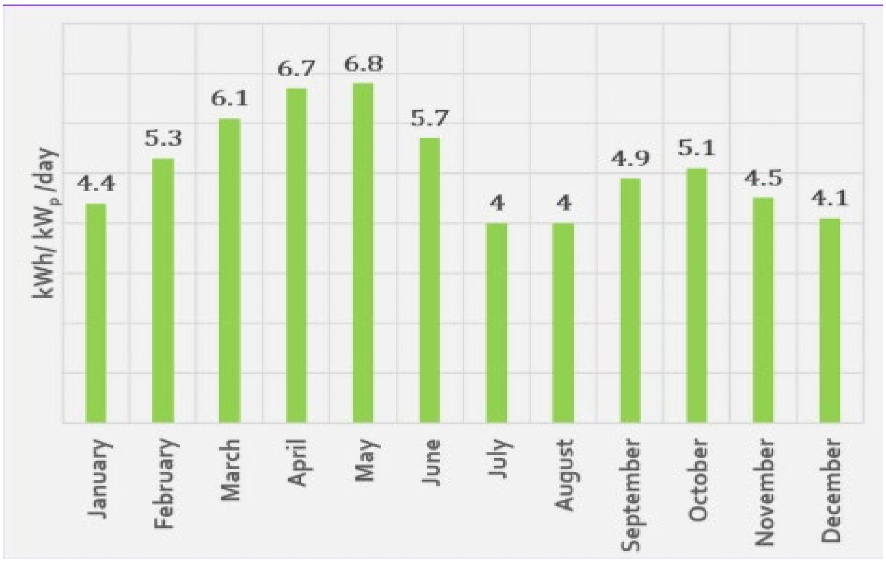


Figure 11. Monthly average daily generation per kW peak capacity of PV plant in India

GRID TIED INVERTER

An inverter converts DC power into AC power and synchronises the output AC power with the available grid's phase, frequency, and voltage to feed the PV power into the grid (See Figure 12). The inverter is one of the most expensive components in the PV system, costing around 4 to 5 Rs per Watt. It usually functions when connected with a reliable three-phase power. But when there is a fluctuation in the grid or phase loss, the inverter is designed so that it shuts itself down and stops generating PV power. This functionality is called anti-islanding. The inverter also stops generating power when the grid voltage and frequency are beyond the acceptable range.

Figure 12. A grid-tied inverter for converting DC to AC
photo: GERMI

MODULE MOUNTING STRUCTURE

The Mounting Structure (MMS) is used to mount PV modules at a location where no shadows fall on them during the daytime (see Figure 13). The PV modules should face the sun at noon to collect maximum sunlight. That is why they are oriented south. PV modules should be kept at an optimal tilt angle, which depends on the installation site and is usually determined by the solar agency. (20-25 degrees).

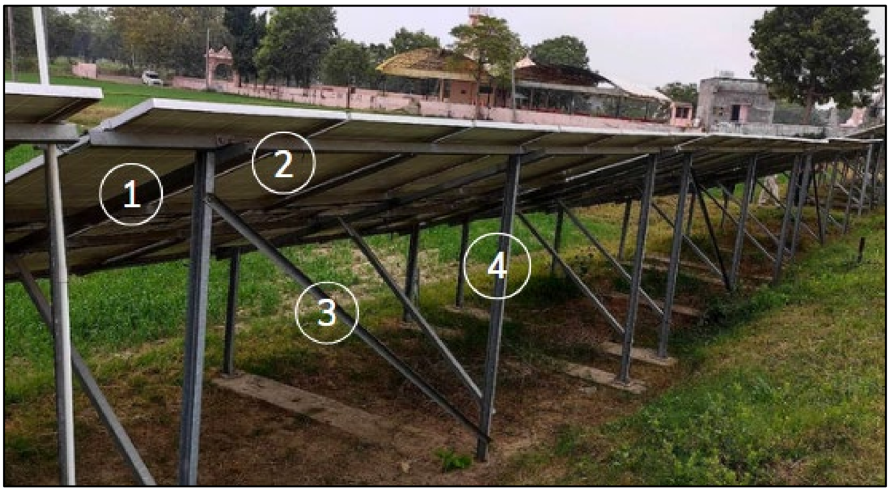


Figure 13. Module mounting structure with different components: (1) RAFTER; (2) PURLIN; (3) BRACING; (4) LEG
photo: GERMI

SOLAR DC CABLE

(See Figure 14) DC cable carries DC from the PV modules right up to the inverter. The typical size of a DC cable is 4 sq. mm from PV modules to DC distribution box (DCDB), while thicker DC cables connect the inverter to DCDB (depending on the inverter's rating). DC Cable is made of tin-plated copper to protect it from corrosion and is doubly insulated for UV protection. MC4 connectors connect positive and negative DC cables. IP65 rating ensures the connection stays moisture-free in the rainy season.

Figure 14. Solar DC cable types used in PV module
Source: GERMI

SOLAR AC CABLE

Figure 15 represents the AC cables which can be made either from copper or aluminum. Usually, the cable is laid underground in the field. Armored cable is used to protect it from any mechanical damage, rocks, or excavation.

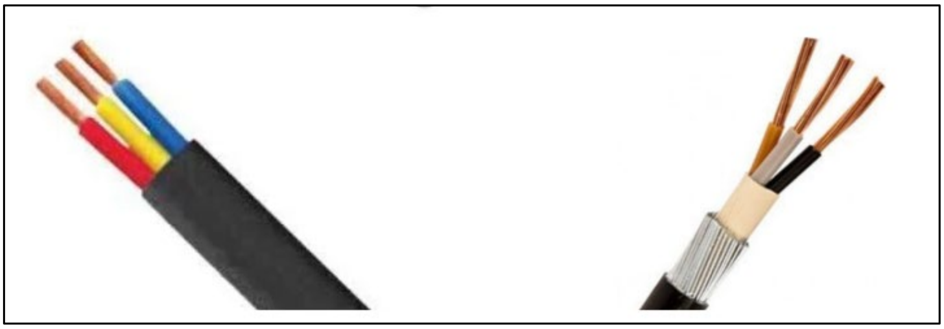


Figure 15. AC cables carry AC from the inverter to the AC distribution box (ACDB).
Source: GERMI

PROTECTION DEVICES

Fuse provides safety against overcurrent that could otherwise damage the cables or inverter. The fuse cartridge and the cylindrical fuse are used for the PV system, while the kit kat fuse is used at the metering side (AC system) Miniature Circuit Breaker (MCB) protects the electrical appliances from overloading and short circuits. Surge Protection Device (SPD) protects the system from sudden high voltages (see Figure 16).

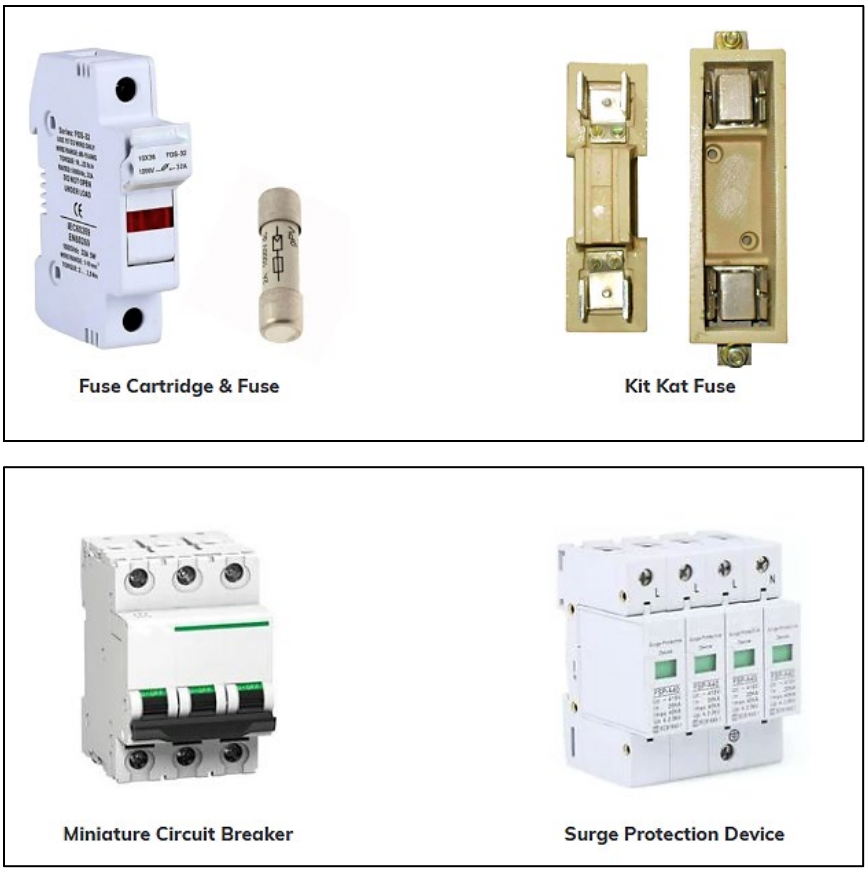


Figure 16. Different sets of fuses used in PV module systems. (*Source:* GERMI)

DC DISTRIBUTION BOX (DCDB)

If the inverter has enough DC input terminals and surge and overcurrent protection capabilities, then the DCDB can be evaded entirely in the PV system. DCDB should be weather resistant (>IP 65) as it is typically installed outdoors (See Figure 17).

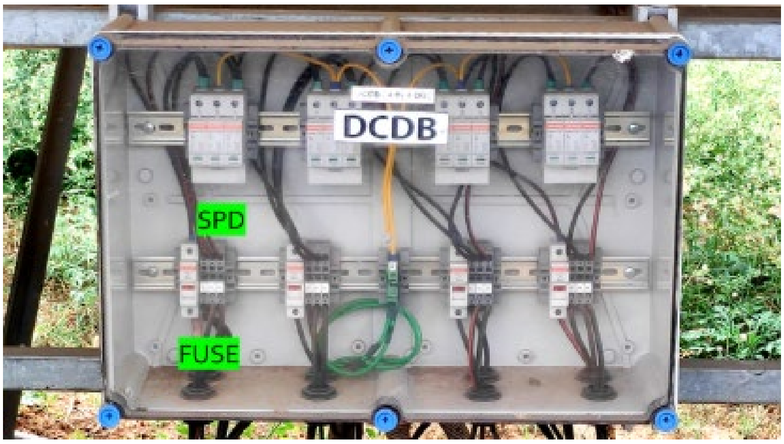


Figure 17. DCDB distribution box
photo: GERMI

AC DISTRIBUTION BOX (ACDB)

First, the inverter AC output passes through the AC Distribution box (ACDB) and is then fed to the load and/or grid. Three different-coloured lights indicate the availability of three phases (See Figure 18). If any of the three lights are off, that phase is unavailable, and the inverter will stop supplying power to the grid.

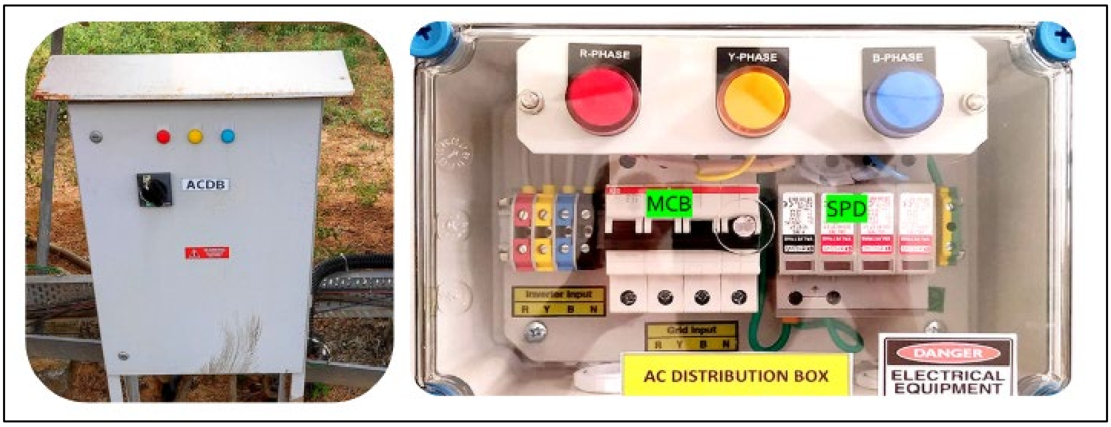


Figure 18. AC distribution box
photo: GERMI

EARTHING AND LIGHTNING PROTECTION

Lightning Arrestor (LA) protects the PV plant from lightning strikes. LA provides a safe path for the lightning current to discharge into the earth (see Figure 19). Earthing protects the human body from fatal shocks when insulation is damaged on live cables. There should be separate Earth Pits for DC Earthing, AC Earthing, and LA. LA earthing wire must be at least 16 sq. mm copper or 25 sq. mm GI.

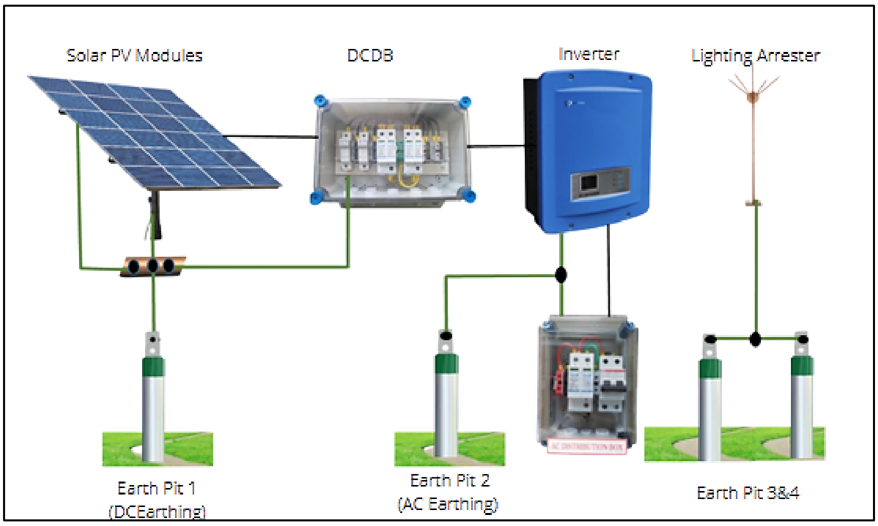


Figure 19. Earthing and Lighting setup for a PV system
Source: GERMI

METERING

Figure 20 represents a net metering system typically associated with grid-connected systems. The three main components for the Net metering setup are as follows:

1. Solar Generation Meter/Check Meter: It shows the energy generated by Solar PV modules and units in kWh.
2. Consumption Meter: It shows the energy consumed by the pump motor and units in kWh.
3. Net Meter: It is a bidirectional meter that shows three things:
    a. energy injected into the grid (export) in kWh
    b. energy drawn from the grid (import) in kWh
    c. the net energy (export-import) in kWh.

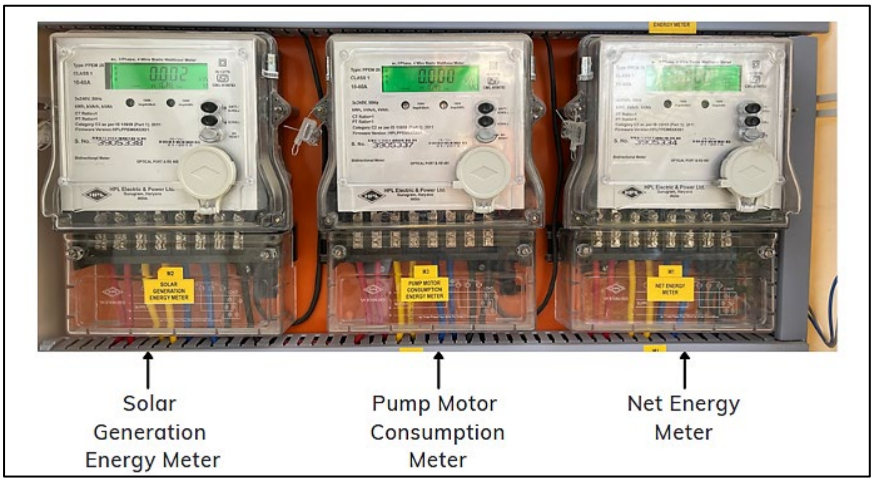


Figure 20. Net-Metering for grid-connected PV systems
photo: GERMI

Net meter allows farmers to sell their excess unutilised energy generated by solar modules to the utility grid. They can also draw power from the grid if solar PV modules are not generating enough to operate the solar pump. Farmer earns a fixed revenue (also called "Feed-in Tariff") for every unit of net energy (export-import) injected into the grid. After deducting the loan instalment and feeder loss from this earned revenue at the end of the billing cycle, the farmer is paid the remaining amount. In case the net energy (import-export) is drawn from the grid (i.e., the import is more than the export), then, at the end of the billing cycle, the farmer has to pay an amount to the utility grid for the net units drawn, loan instalment and feeder loss.

3.3 Maintenance, Troubleshooting, and Efficiency Optimisation

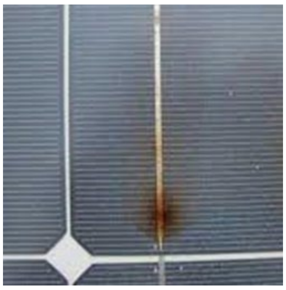
Operation & Maintenance (O&M) is critical for the long-term performance, reliability, and safety of solar irrigation pump systems (see Figure 21). Therefore, for optimal performance, routine maintenance is required. The basic or bare minimum that one should consider as part of the routine maintenance is listed in Table 5.

Figure 21. Significance of O&M for a solar PV system (*Source*: Authors' description)

Table 5. Routine maintenance activity for optimal performance of PV systems

Activity	Frequency	Remarks
Cleaning of solar panels	Every 1–2 weeks	Dust and bird droppings reduce efficiency by 10–20%
Checking wiring and connections	Monthly	Inspect for loose connections, corrosion, or wear
Inspecting motor and pump	Quarterly	Check for abnormal noise, vibrations, or leakage
Structural inspection	Every 6 months	Ensure bolts and mounts are tight and rust-free
Controller/inverter maintenance	As per manufacturer	Usually dusting and parameter checking

Routine maintenance practices for PV systems that are listed above are the bare minimum and often insufficient to address the full range of operational risks. Beyond basic upkeep, several persistent, often overlooked issues can significantly impair module performance if left unaddressed. As illustrated in Figure 22, factors such as material degradation, environmental exposure, and mechanical damage collectively reduce energy output and system efficiency. These include corrosion-induced hotspots, encapsulant deterioration, physical breakages, insulation failures, and external obstructions like dust, bird droppings, and shading. Together, these conditions highlight the need for more comprehensive monitoring and maintenance to sustain optimal PV performance over time.

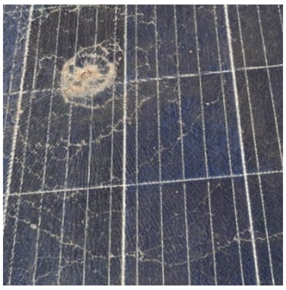


(A) Corroded Busbars

Corroded busbars create hot spots in the module, which further degrades the solar cell and back sheet.

(B) EVA Browning

Browning of EVA encapsulant decreases reflectivity and impacts energy generation.



(C) Broken Glass

Broken glass reduces light absorbed by the module; water and dust can penetrate under the glass.

(D) Insulation Failure

When electrical insulation is compromised, it facilitates moisture ingress, leading to corrosion, electrical shorts, arcs, and module fires.

(E) Dust Accumulation

Dust accumulation blocks radiation, reducing energy generation and efficiency.

(F) Bird Droppings

Bird droppings cast shadows on modules, creating localised hotspots and potentially complete damage.

(G) Tree Shading

Trees adjacent to the PV system (except in the north direction) will cast shadows on modules.

Figure 22. (A)-(G) shows various reasons for the lack of performance of the PV module.
photo: GERMI

Beyond the routine issues captured in Table 6, PV-based pumping systems often encounter less visible but equally critical operational challenges that can undermine performance over time. These include gradual efficiency losses due to component ageing, undetected wiring degradation, and suboptimal system calibration, which may not immediately trigger system failure but reduce overall output. Environmental factors such as fluctuating irradiance, temperature stress, and site-specific conditions can further compound these effects. Addressing such issues requires a more proactive approach to diagnostics, including periodic performance benchmarking, preventive maintenance, and system-level checks to ensure sustained efficiency and reliability.

Table 6. common trouble shooting scenarios related to PV systems

Problem	Likely Cause	Suggested Action
Low or no water output	Dirty panels, low sun, motor/pump issue	Clean panels, check sun hours, and verify motor operation
System not starting	Fuse blown, controller fault, loose wiring	Replace fuse, reset controller, inspect wiring
Intermittent performance	Shading, inverter overheating	Remove shading, ensure proper inverter ventilation
Excessive pump noise or vibration	Mechanical fault, misalignment	Contact service technician, realign pump-motor assembly

Efficiency Optimisation Tips

I. **Panel Cleaning**: Regular cleaning can restore up to 15–20% of lost output.

II. **Use of Storage Tanks**: Allows water to be pumped during peak sun hours and used later.

III. **Micro-irrigation Integration**: Drip or sprinkler systems improve water use efficiency by 40–60%.

IV. **MPPT Controllers**: Enhance system performance under varying sunlight conditions.

V. **Seasonal Tilt Adjustment**: Adjust panel tilt twice a year (summer/winter) to optimise solar capture.

Financial and Economic Aspects of Solar Irrigation Pump Adoption

4. Financial and Economic Aspects of SIP Adoption

4.1 Cost-Benefit Analysis for Farmers

The financial attractiveness of Solar Irrigation Pumps is a key driver of adoption, especially in regions where grid electricity access is limited or diesel prices are high. A well-structured cost-benefit analysis helps farmers make informed decisions regarding the upfront investment and long-term savings.

Why is uptake slower than expected (even with high subsidies)

1) Capital & Cash-Flow Constraints

- **High upfront burden**: Even with 90% subsidies, farmers must pay 10% of the ₹2.0–2.5 lakh system cost upfront (₹20,000–25,000), plus wiring, foundations, and paperwork, all before subsidy reimbursement.
- **Working capital clash:** The solar payment window often coincides with peak outlays for seeds, fertiliser, and labour, stretching already thin cash flows.
- **Credit frictions:** KYC checks, collateral demands, and cautious lending slow disbursals. Small and marginal farmers, wary of debt for a non-crop input, often opt out.

2) Information & Trust Gaps

- **Unclear economics:** Farmers struggle to translate kW, kWh, FiT, and net-metering credits into seasonal rupee savings or earnings.
- **Performance anxiety**: Concerns about low generation in monsoon/winter, shading losses, theft, and repair responsibilities undermine confidence.
- **Export credit confusion**: In states like UP, surplus export earns credits only when the feeder is live. In areas with frequent outages, actual credits fall far short of brochure promises, leading to frustration and delays in adoption.
- **Low awareness**: At present, only 23% of farmers are aware of Component B and 11% of Component C1. Awareness of subsidies is even lower, just 10% for Component B and 6% for Component C1, limiting uptake.

3) Operational Risks

- **Water-first logic:** With unreliable supply, irrigation needs trump energy export; diesel pumps are often retained as backups.
- **Maintenance discipline:** Panel cleaning, inverter upkeep, and earthing are perceived as extra chores with uncertain payoff.
- **Site constraints:** Limited shade-free space near pumps forces longer DC cable runs, raising costs and transmission losses.

4) Programme Frictions

- **Administrative bottlenecks:** Online registration, DISCOM feasibility checks, approvals, and inspections stretch timelines; missing a crop season dampens enthusiasm.
- **Vendor variability**: uneven contractor quality, spare parts scarcity, and weak after-sales service erode trust and word-of-mouth momentum.

Why do farmers still hesitate?

Uttar Pradesh (C1 – grid-connected pump solarisation)

- Farmers are offered very high subsidies (often around 90%), making upfront adoption costs relatively low.
- However, many farmers only later realise that export credits for surplus solar power accrue only when the village feeder supply is switched on.
- In feeder areas with frequent power outages, the actual credits received are significantly lower than those advertised in program brochures.
- This gap between expected and realised benefits has led many farmers to delay or postpone adoption.

Capital Costs For the Solarisation of a grid-connected individual agriculture pump

This section develops a representative 5 HP irrigation scenario for Uttar Pradesh to evaluate the techno-economic implications of solar pump adoption under MNRE benchmarks. Table 7 outlines benchmark capital costs, which are used in Table 8 to estimate total system costs for a grid-connected SIP. Table 9 presents the technical assumptions underpinning system performance. Based on these inputs, Table 10 reports the projected net energy surplus over a 10-year period, while Table 11 estimates the annual cost of diesel-based irrigation. Together, these provide the basis for comparing the financial and energy outcomes of solar versus diesel irrigation systems.

Table 7. Benchmark Cost (MNRE Order, dated 04-09-2023)

Capacity	Above 1kW to 3kW	Above 3kW to 6kW	Above 6kW to 10kW
Benchmark cost (Rs/kW) without GST	51,003	44,702	43,975

Note: The above benchmark costs are inclusive of the total system cost, installation, commissioning, transportation, insurance, warranty/guarantee, monitoring, and maintenance for five years.

1. Example Scenario (Uttar Pradesh): For a grid-connected solar pump system

- Current System: 5 HP diesel pump (3.7 kW)
- Proposed System: 5 HP Solar Surface Pump System (7.4 kW solar system)

Table 8. Cost of a 5 HP Solar Irrigation Pump in UP

Component	Cost (Rs)	Details
From 6kW to 10kW	Rs 43,975	Cost per kW
5 HP Solar Pump system cost (7.49 kW)	Rs 3,29,373	As per the Benchmark cost by MNRE

Total SIP System Cost = Rs 4,04,460

Let us consider a 5 HP solar pump system, where the farmer is allowed to install up to 10 HP (7.4 kW) of solar capacity (2× the pump capacity), as per scheme guidelines. The technical assumptions are listed in Table 9, based on the scheme guidelines and contextualized for Uttar Pradesh.

Table 9. Key Technical Assumptions for Solar Irrigation Pump (SIP) Analysis in Uttar Pradesh

Key Technical Assumptions (Conservative, Realistic for UP)
• Peak sun hours: 4.5 hours/day | Performance Ratio:100%
• Average Generation: 4.5 kWh/kW/day | Total System Capacity: 7.49 kW
• System Net Energy Generation: 33.71 kWh/day | Annual: 12,134 kWh/year
• System Degradation: 0.70% per year
• Pump Capacity: 5 HP = 3.745 kW | Pump electricity consumption: 2,247 kWh/year (120 days)
• Net Energy Surplus in Year 1: 9,887 kWh

Table 10. Annual Net Energy Surplus Over 10 Years (5 HP SIP System)

	Year	1	2	3	4	5	6	7	8	9	10
Net Energy Surplus	kWh	9887	9818	9749	9681	9613	9546	9479	9412	9347	9281

B. Annual Cost of Using Diesel Pump (Existing Practice)

Table 11. Diesel Pump Cost Calculation

Diesel consumption	1.07 litres/hour
Diesel rate	Rs 90/litre
Operating hours	5 hours/day
Irrigation season	120 days/year (June to September)
Total pump usage	600 hours/year
Diesel use per year	642 litres (1.07 × 600)
Total annual diesel cost	Rs 57,780 (642 × Rs 90)

4.2 Long-Term Financial Viability and Return on Investment

4.2.1 Example Scenario: For Grid-connected solar pump system (PM-KUSUM Component C1) (see Table 12)

Table 12. 10-Year ROI projections

	Year	0	1	2	3	4	5	6	7	8	9	10
Net Energy Surplus Revenue	kWh		9887	9818	9749	9681	9613	9546	9479	9412	9347	9281
Tariff/Saving Rate (Feed in tariff)	Rs./kWh		2	2	2	2	2	2	2	2	2	2
Surplus energy generation Revenue	Rs.		19,774	19,636	19,498	19,362	19,226	19,092	18,958	18,824	18,694	18,562
Payback	Rs.	-32,937	-	-	-	-	-	-	-	-	-	-
Gross Revenue / Saving			19,774	19,636	19,498	19,362	19,226	19,092	18,958	18,824	18,694	18,562

Key Takeaways

- Total 10-Year Net Return: Rs 1,91,624
- Initial Farmer Cost: Rs 32,937
- Net Profit Over 10 Years: Rs 1,58,687 — with payback typically within 2 years

In Uttar Pradesh, the adoption of Solar Irrigation Pumps (SIPs) offers both **cost savings** and **income generation**, particularly under **Component C1 of PM-KUSUM**. Farmers can:

- **Reduce irrigation costs significantly**
- **Recover their investment within 2 year**
- **Earn over ₹1.5 lakh in net profit over 10 years**

4.2.2 Example Scenario: For an off-grid solar pump system

ROI Calculation — Component B (Off-Grid Solar Pump) (see Table 13)

Table 13. 10-Year Financial Summary — Component B Off-Grid Pump

Annual diesel savings (Year 1)	Rs 57,780
Total 10-year diesel savings	Rs 5,77,800
Initial system cost (farmer share)	Rs 1,31,748
Net Profit over 10 years	Rs 4,46,052

Key Takeaways

In Uttar Pradesh, the adoption of Solar Irrigation Pumps (SIPs) offers both **cost savings** and **income generation**, also in **Component B of PM-KUSUM**. Farmers can:

- **Reduce irrigation costs significantly**
- **Recover their investment within 3 year**
- **Earn over ₹4 lakh in net profit over 10 years**

SIPs therefore represent a financially attractive and sustainable option for small and medium farmers, especially when supported through appropriate credit mechanisms, enabling policies, and effective DISCOM buyback implementation.

Other positive gains

Economic Resilience: Sips offer more than just savings — they strengthen the farmer's overall economic position:

- **Reduced Crop Losses:**
  - Delays in diesel supply or power cuts often hurt crop yields.
  - With solar, farmers get timely and reliable irrigation, reducing losses.
- **Stable Operating Costs:**
  - After the initial cost, the operating cost is almost zero.
  - No fuel price fluctuation, no monthly electricity bills — leading to predictable cash flows.
- **Improved Creditworthiness:**
  - Owning a solar pump is a long-term asset.
  - Regular savings or income from power export improve a farmer's financial profile.
  - This can enhance access to loans or credit from banks or cooperatives.

4.3 Credit and Financing Options

Despite long-term benefits, the upfront cost of SIPs can be a barrier for small and marginal farmers. To address this, the Government and financial institutions offer several support mechanisms.

o **Subsidies and Grants**

Under **PM-KUSUM (Component C1)**:

- **Central Financial Assistance (CFA):** Up to 30% of system cost
- **State Government Subsidy:** Additional 60% (for *Uttar Pradesh;* varies by State)
- **Farmer's Share:** 10% of the total cost

1. Example Scenario: Under KUSUM Component C1 (for Grid-connected solar pump system)

As shown in Table 14, the cost-sharing structure under KUSUM Component C1 for a grid-connected solar pump system includes contributions from both the government and the farmer.

Table 14. Cost-sharing structure under KUSUM Component C1 for grid-connected solar pump systems

Component	% Share	Value
Central and State Govt Subsidy	90%	2,96,436
Farmer's Share	10%	32,937
Total System Cost	100%	3,29,373

o **Loan and Credit Support**

Banks and cooperative societies provide soft loans to eligible farmers under priority sector lending. Table 15 outlines key financing options available to farmers for the adoption of SIP

Table 15. Financing options for adoption of SIP

Scheme	Details
Kisan Credit Card (KCC)	Flexible credit for agri-related investment
NABARD Refinance Scheme	Interest subvention available through Rural Banks
Bank Loans	Effective interest rate (approx.): 12.5% per annum (based on 1-Year MCLR + 350 bps).
Government Banks offering subsidy	Provided by Union Bank of India, State Bank of India, Canara Bank, Bank of India.

4.4 PM-KUSUM B & C1 in UP: Subsidy and Financial Support

Tables 16 and 17 present the extent of subsidy support available under PM-KUSUM Components B and C1 across various pump capacities and pump types. These tables serve as a useful reference for addressing specific queries from farmers, who often seek information on subsidy provisions tailored to their individual pump specifications.

Table 16. Pump capacity-wise Solar pump Subsidy under PM-KUSUM Component B

Pump Capacity (HP)	Pump Type	State Govt Subsidy (₹)	Central Govt Subsidy (₹)	Total Subsidy (₹)
2 HP	AC/DC Surface	56,737	41,856	98,593
2 HP	DC Submersible	—		1,00,215
2 HP	AC Submersible	—		99,947
3 HP	AC/DC Submersible	77,618	54,696	1,32,314
3 HP	AC Submersible	77,618	54,696	1,32,314
5 HP	AC Submersible	—		1,88,038
7.5 HP	AC Submersible	1,40,780	1,14,203	2,54,983
10 HP	AC Submersible	1,40,780	1,14,203	2,54,983

Source: UP Agriculture Department (URL: https://www.hindustantimes.com/cities/lucknow-news/pm-kusum-scheme-govt-to-provide-over-40k-subsidised-solar-pumps-to-up-farmers-101764266233843.html)

Note: Farmers taking a bank loan can get a 3% interest rebate from both the central and state governments (6% in total) under the Agricultural Infrastructure Fund (AIF), if they pay their own share of the investment.

Table 17. Pump capacity-wise solar power plant cost distribution in Uttar Pradesh under component C1

Pump Capacity (hp)	Solar Power Plant capacity (kW)	Rate per plant, including GST (INR)	Subsidy and farmer's contribution per plant (INR)			Farmer's share
			Central government	State government	Total grant	-10%
			-30%	-60%		
3	4.5	239000/-	71700/-	143400/-	215100/-	23900/-
5	7.5	393250/-	117975/-	235950/-	353925/-	39325/-
7.5	11.2	548000/-	164400/-	328800/-	493200/-	54800/-
10	14.9	719950/-	164400/-	328800/-	493200/-	226750/-

Source: UPNEDA

Overview:

Based on the estimation and projections, in Uttar Pradesh, the adoption of Solar Irrigation Pumps (SIPs) offers both cost savings and income generation. See Table 18, which summarises the overall impact of Solar Irrigation Pumps (SIPs) across two implementation pathways, PM-KUSUM Component B and Component C1, highlighting cost savings, investment recovery, and long-term profitability.

Table 18. Summary of Economic Impacts of Solar Irrigation Pumps (SIPs) under PM-KUSUM Components B and C1

Impact Area	Outcome	
	PM KUSUM C1	PM KUSUM B
Cost	Significant reduction in irrigation costs	Significant reduction in irrigation costs
Investment recovery	within 2 year	within 3 year
Profitability	Earn over ₹1.5 lakh in net profit over 10 years	Earn over ₹4 lakh in net profit over 10 years

SIPs therefore represent a financially attractive and sustainable option for small and medium farmers, especially when supported through appropriate credit mechanisms, enabling policies, and effective DISCOM buyback implementation.

Gender and Social Inclusion (GESI) in Solar Energy Adoption

5. Gender and Social Inclusion in Solar Energy Adoption

5.1 Importance of Women's Participation in Renewable Energy Programs

In rural India, women play a central role in agricultural activities, yet their involvement in technology adoption, particularly in renewable energy, has often been limited due to systemic gender disparities. The adoption of SIPs under schemes like PM-KUSUM presents an opportunity to address this imbalance and promote inclusive development.

Agriculture is a collective effort-it involves not just individual farmers, but entire families and communities. Women play a crucial role in farming activities, managing water resources, and utilising energy for household and agricultural needs.

In practice, small and marginal farmers, particularly those from Scheduled Castes (SC), Scheduled Tribes (ST), and other socially disadvantaged groups, frequently face challenges in accessing government schemes. These challenges include lack of awareness, difficulty navigating online application systems, and limited access to required documentation. Additionally, women's in the context of Uttar Pradesh lacks decision-making power in technology choices (eg. SIP).

For PM-KUSUM to be effective and equitable, there must be focused efforts to improve outreach and accessibility for these groups-especially through local awareness drives, handholding support, and simplified procedures. While inclusion of women and marginalised communities remains a stated policy goal, its actual implementation on the ground varies widely by region.

Why GESI (Gender Equality and Social Inclusion) is Important

- **Energy access is not gender-neutral:** Women and men experience energy needs differently because of their roles in agriculture, household work, and income generation.
- **Inclusive renewable energy programs improve impact:** Involving women ensures solutions are more widely adopted, better maintained, and lead to greater social and economic returns.
- **Evidence from global programs:** Studies by UNDP and IRENA show that women-led renewable energy initiatives have higher repayment rates for loans, improved technology adoption, and enhanced livelihood outcomes.
- **GESI aligns with Sustainable Development Goals (SDGs):** Integrating women and marginalised groups into energy value chains supports SDG 5 (Gender Equality) and SDG 7 (Affordable and Clean Energy) simultaneously.

Recognizing the Power of Women Farmers

- Over 1,000 rural women entrepreneurs in Uttar Pradesh, supported through SHGs under the UPSRLM, have collectively installed more than 4 MW of decentralized solar energy, running businesses like flour mills, tailoring units, stores, and dairies, creating alternative incomes and reducing reliance on diesel.
- The expansion of Self-Help Groups (SHGs) under **DAY-NRLM** highlights women's active participation in community development.
- In **Uttar Pradesh**, **94.9 lakh households** have been mobilized into **8.4 lakh SHGs** (PIB, 2024).
- These SHGs provide **collective platforms** that can help women **access renewable energy initiatives**, including schemes like PM-KUSUM.

5.2 Challenges Faced by Women & Marginalized Groups

- **Information Gap**: Lack of awareness about schemes, technical knowledge, or application processes.
- **Access to Finance**: Difficulty in meeting collateral requirements or navigating banking procedures.
- *E.g.: In Mandla (district), MP, only 28% women were aware of SIPs, and just 5% knew about PM-KUSUM. Key adoption barriers included lack of technical training(74%) and high upfront costs (43%).*
- **Land Ownership**: Women often lack formal land titles, which can be a barrier for scheme eligibility or accessing loans.
- **Decision-Making Power**: Limited say in household or community decisions regarding technology adoption or finances.
- **Mobility & Time Constraints**: Household duties may limit their ability to attend meetings or travel for applications.

Evidence from Mandla, Madhya Pradesh

Evidence from Mandla highlights that SIP adoption is constrained less by technology and more by structural and information barriers. As shown in Figure 23, landownership (31.3%) and lack of training/technical knowledge (30.3%) are the dominant constraints, followed by financial barriers (22.9%). Gendered control over assets and decisions persists, with men often owning SIPs (12.4%) and leading irrigation decisions (9.0%). In contrast, Figure 24 shows that the most critical enablers are awareness and information (38.8%) and locally grounded training through female technicians such as KUSUM Mitras (29.9), indicating that knowledge and institutional support outweigh purely financial interventions.

Beyond adoption, SIPs generate measurable welfare gains through time savings and livelihood shifts. Figure 25 shows that a majority of women report significant reductions in irrigation time (58.7%), with only a small share experiencing no change (18.1%), enabling reallocation toward productive activities. This translates into diversification of income sources, as seen in Figure 26, where women predominantly engage in livestock rearing (43.9%), followed by tailoring (18.1%) and water selling (9.2%). Together, these patterns indicate that SIPs function not only as an irrigation technology but as a lever for enhancing women's economic participation and agency.

Adoption Barriers

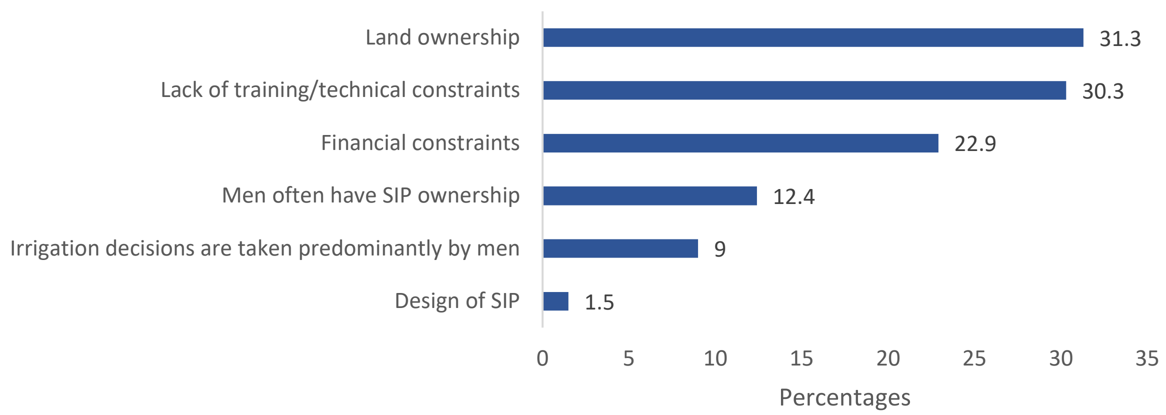


Figure 23. Denotes the various adoption barriers to Solar PV systems, exhibiting a case from Mandla, Madhya Pradesh (*Source:* IWMI's baseline survey in Mandla, Madhya Pradesh 2024)

Need based required support

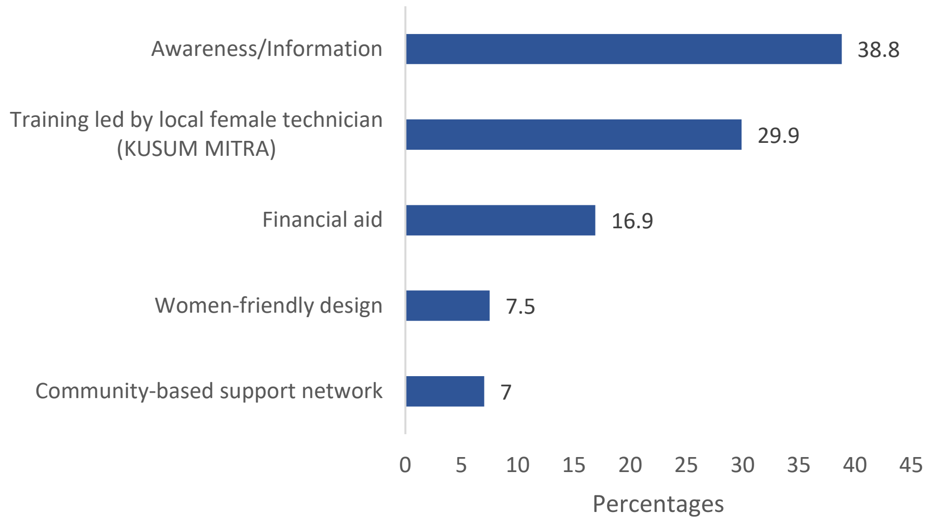


Figure 24. Denotes the needs-based support for Solar PV systems, exhibiting a case from Mandla, Madhya Pradesh)
Source: IWMI's baseline survey in Mandla, Madhya Pradesh (2024)

How SIPs help women reallocate time to other income-generating activities

(Example from Mandla, Madhya Pradesh)

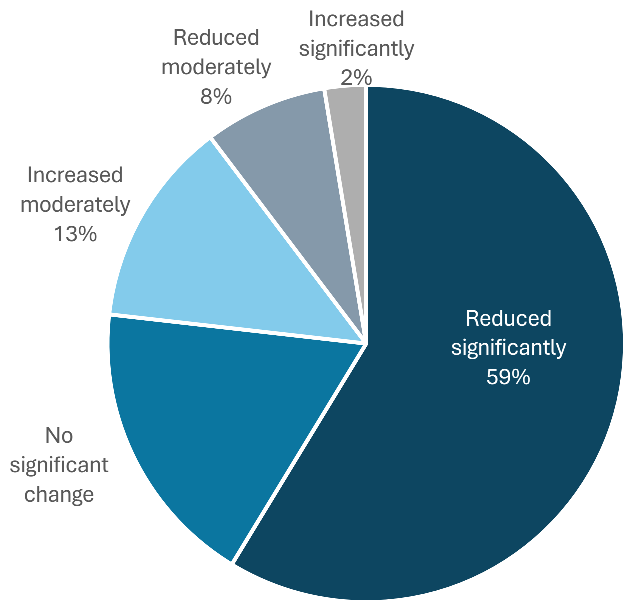


Figure 25. Denotes the positive impacts on how SIP help women reallocate time to generate other income-generating activities exhibiting a case from Mandla, Madhya Pradesh)
Source: IWMI's baseline survey in Mandla, Madhya Pradesh (2024)

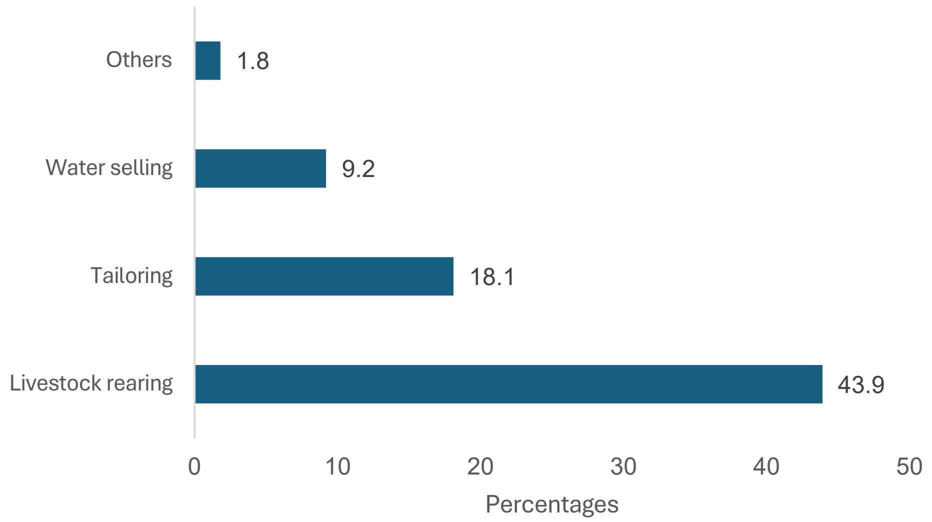


Figure 26. Activities undertaken by women in Mandla, MP, enabled by moderate to significant irrigation time savings following SIP installation.
Source: IWMI's baseline survey in Mandla, Madhya Pradesh (2024)

5.3 Role of "Mahila KUSUM Mitras or Women Extension Agents" in Supporting Women Farmers

Recognising the importance of grassroots support, the PM-KUSUM scheme encourages the mobilisation of **"Mahila KUSUM Mitras"**—local women trained to act as facilitators and promoters of solar irrigation.

Who are Mahila KUSUM Mitras?

These are women selected from rural communities, extension agents, or from SHGs or women's federations, who are trained to:

- Raise awareness about solar irrigation among fellow women farmers.
- Assist with application processes, documentation, and liaising with Government departments or DISCOMs.
- Facilitate training and demonstrations on SIP installation and maintenance.
- Support operations through routine monitoring and troubleshooting.
- Ensuring Women's Voices are Heard: These roles not only create local employment opportunities for women but also ensure that women's perspectives and needs are represented in the implementation of the program.

Impact of Mahila KUSUM Mitras

- Bridges the gender gap by making information and services accessible to women.
- Creates employment and income opportunities for rural women.
- Builds local capacity and encourages ownership of technology by women farmers.
- Improves adoption rates through trust-based, peer-led engagement.

Effective Farmer Outreach and Awareness Strategies

6. Effective Farmer Outreach and Awareness Strategies

6.1 Role of Krishi Vigyan Kendras (KVKs) in Farmer Education

Krishi Vigyan Kendras (KVKs) are frontline agricultural extension centers under the Indian Council of Agricultural Research (ICAR) and play a pivotal role in technology dissemination at the grassroots level.

Uttar Pradesh has a robust network of KVKs affiliated with State agricultural universities (like CSAUK Kanpur, NDUAT Ayodhya, SVPUAT Meerut, BUAT Banda) and ICAR.

Demonstration Units for Practical Learning

Subsequently, solar pump demonstration units should be installed at selected KVKs across different agro-climatic zones. These units will serve as live models for farmers to observe the performance, operation, and maintenance of solar pumps, thereby enhancing confidence in adoption.

Farmer Training and Field Engagement

KVKs should regularly organise training sessions and field days at the village level to directly engage with farmers. These sessions must use local languages and dialects, supported by visual and audio tools, to ensure that the messaging is inclusive and effective.

Collaboration with Local Agencies

Strong partnerships between KVKs, UPNEDA, and local Panchayats will be critical for joint outreach, farmer mobilisation, and to disseminate information about Government schemes and subsidies.

Monitoring, Feedback, and Reporting

Moreover, each KVK should maintain records on the number of farmers trained, pump adoptions, and feedback received. This data should be periodically reported to UPNEDA and ICAR to guide policy refinements and resource allocation.

Functions of KVKs in SIP Promotion:

- **Training and Demonstrations:** KVKs organise training programs and on-farm demonstrations on solar pump operation, benefits, and maintenance.
- **Farmer Awareness Camps:** Periodic events conducted by KVKs create awareness about the PM-KUSUM scheme and available subsidies.
- **Technical Support:** KVK staff can assist in site assessments, selection of suitable pump capacity, and troubleshooting.
- **Linking with Institutions:** They act as a bridge between farmers, Government agencies, DISCOMs, and financial institutions.
- **Feedback Mechanism:** KVKs collect farmer feedback and communicate it to policymakers for scheme improvement.

KVKs as Trusted Facilitators:

Because they are region-specific and locally managed, KVKs enjoy credibility and trust among farmers—making them ideal partners in SIP adoption campaigns.

6.2. How Jan Seva Kendras Assist in the Application Process

Jan Seva Kendras (JSKs), also known as **Citizen Service Centres (CSCs)**, are crucial touchpoints for delivering public services in rural India. In the context of **Solar Irrigation Pump (SIP)** adoption, these centres provide last-mile connectivity to farmers, especially those who face digital or procedural barriers.

Key Functions of JSKs in SIP Facilitation:

- **Online Application Support:**
    - Many SIP schemes, especially under **Component C of the PM-KUSUM**, require online registration.
    - JSK operators help farmers upload necessary documents (land records, Aadhaar, bank details, etc.) and complete digital forms on Government portals.
- **Document Verification Assistance:**
    - Staff at JSKs help farmers prepare required documentation, ensuring compliance with eligibility criteria.
    - They often liaise with local revenue officers and DISCOMs to streamline approvals.
- **Tracking and Status Updates:**
    - JSKs provide farmers with application tracking services, alerting them of approval, subsidy disbursement, or further actions required.
- **Grievance Redressal:**
    - Farmers can register issues or delays in the system through the help of JSKs, which act as intermediaries between rural applicants and Government authorities.

Organising Camps for Farmer Support

To increase visibility and access to SIP schemes, **Jan Seva Kendras often collaborate with Government departments to organise dedicated outreach and registration camps**.

Features of SIP-Centric Camps:

- **Awareness Sessions:**
    - Inform farmers about the benefits of solar pumps, PM-KUSUM scheme components, and financial incentives.
- **On-the-Spot Registration:**
    - Mobile laptops, printers, and biometric devices enable real-time enrollment and document submission.
- **Expert Consultations:**
    - Representatives from DISCOMs, renewable energy agencies, and solar vendors often attend to address queries.
- **Local Demonstrations:**
    - Mini SIP models or videos may be showcased to explain system functionality and technical requirements.

- **Strategic Locations:**
    - Camps are organised near **weekly haats, panchayat offices, agricultural mandis, or KVKs**, ensuring accessibility for target beneficiaries.

These camps not only **demystify the application process** but also help identify and support farmers who may otherwise remain excluded due to literacy or mobility constraints.

Addressing Common Challenges in Accessing Subsidies

Despite generous subsidies under the **PM-KUSUM scheme**, many farmers face bottlenecks in availing the financial benefits. Jan Seva Kendras serve as critical bridges to help overcome these obstacles.

JSK's Mitigating Role:

- **Handholding Support:**
    - JSKs walk farmers through each application stage, ensuring documentation is correct and complete.
- **Real-Time Problem Solving:**
    - By maintaining direct contact with district-level energy offices and scheme portals, JSK operators resolve issues quickly.
- **Language and Literacy Aid:**
    - Operators communicate in local languages and assist semi-literate farmers in understanding official requirements.

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