GOGLA

The Voice of the Off-Grid Solar Energy Industry

Productive Use of Renewable Energy in the Agriculture Value Chain: Market Assessment India

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IKEA Foundation

PMANIFOLD

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Abbreviations

APLM	Agricultural Produce and Livestock Marketing (Promotion & Facilitation) Act
BIS	Bureau of Indian Standards
BMC	Bulk Milk Chiller
CEEW	Council on Energy, Environment and Water
CGS	Credit Guarantee Fund Scheme for Micro and Small Enterprises
CSR	Corporate Social Responsibility
DIDF	Dairy Processing and Infrastructure Development Fund
DRE	Distribute Renewable Energy
EPC	Engineering, Procurement and Construction
EU	European Union
FGD	Focus Group Discussion
FMCG	Fast-moving consumer goods
GDP	Gross domestic product
GOI	Government of India
HP	Horsepower
INR	Indian Rupees
IRES	India Residential Energy Survey
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha Evem Utthan Mahabhiyan
LPD	Liters per day
LVDC	Low Voltage Direct Current
MAFD	Ministry of Agriculture and Farmer's Welfare
MFAD	Ministry of Fisheries, Animal Husbandry and Dairy
MNRE	Ministry of New and Renewable Energy
MW	Mega watt
NABARD	National Bank For Agriculture And Rural Development
NDDB	National Dairy Development Board
NPDD	National Program for Dairy Development
NSSO	National Sample Survey Office
NTPC	National Thermal Power Corporation
OEM	Original Equipment Manufacturer
PBI	Procurement Based Incentive
PODF	Producers' Organisation Development Fund
PURE	Productive Use of Renewable Energy
RBI	Reserve Bank of India
ROI	Return on Investment
SAMPADA	Scheme for Agro-Marine Processing and Development of Agro-Processing Clusters
SHFs	Solar Hydroponic Fodder unit
SWP	Solar Water Pump
USD	US Dollar

Executive Summary

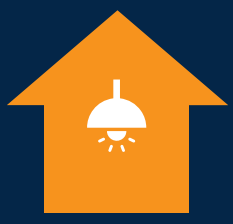
Agriculture is a vital industry in India, employing 50% of the population and contributing 17% of the country's GDP, yet it is hampered by intermittent electricity access in rural regions. India has achieved a 100% household electrification, yet grid reliability, especially in rural areas, remains a pressing issue. This affects the lives and livelihoods of people in these regions and has a significant impact on agriculture.

Off-grid solar productive use of renewable energy (PURE) products can benefit 35 million farmers, boosting their incomes by 20-40%. PURE products like solar water pumps, dryers, grain mills, small horticulture processors, cold storages, refrigerator/deep freezers, bulk milk chillers and vertical fodder growing units can play a crucial role in enhancing agricultural productivity and livelihoods. The market for these technologies is valued at approximately $46 billion, with the potential to increase farmers' incomes by 20-40% and positively impact nearly 35 million farmers, particularly in states like Uttar Pradesh, West Bengal, Gujarat, Madhya Pradesh, and Maharashtra.

The Indian Government has drafted a framework to catalyze PURE adoption, but challenges remain. To help to unlock the opportunity for PURE, the Indian government has drafted a policy framework to boost its adoption, focusing on research and development, financing, skill development, and awareness campaigns. Several challenges impede the widespread adoption of PURE products.

Some of the key challenges include:

- High initial costs for PURE technologies that range from 2 to 13 times more than conventional appliances,
- A limited number of companies selling and distributing PURE products, which curtails both customer access too the technologies and economies of scale,
- Reliance on subsidies to enable customers to purchase PURE products,
- A lack of awareness around PURE by key stakeholders, including financial institutions,
- Underutilization of deployed products.



India has achieved a 100% household electrification, yet grid reliability, especially in rural areas, remains a pressing issue.

Subsidies to promote access to solar water pumps are significant but their success has been hindered due to challenges in implementation. Solar Water Pumps (SWP) are a popular PURE product that can significantly reduce reliance on grid electricity and fossil fuels for agricultural irrigation. SWPs have also gained the attention of the Indian government which offers substantial subsidies for farmers purchasing these products, covering 60-90% of the system cost. However, challenges such as lengthy subsidy application processes, delayed payments to vendors, and insufficient state budget allocations have limited the impact of these subsidies. Alternative business models, like pay-per-use services, are emerging to make SWPs more affordable and create employment opportunities in rural areas.

Awareness around solar cooling solutions remains low, and quality needs to be improved. Solar-based cooling solutions, including cold storages, bulk milk chillers, and refrigerators, can help reduce post-harvest losses in India's agricultural sector. These solutions extend the shelf life of perishable goods, reducing waste and increasing farmers' incomes. However, high upfront costs, lack of product-market fit (i.e., performance and quality) and limited remote monitoring capabilities hinder their adoption. The government offers subsidies to promote these technologies, but awareness among farmers and cooperatives remains low. Innovative business models and coordinated efforts are needed to expand the use of solar cooling technologies.

Knowledge gaps are limiting engagement with Government schemes to accelerate use of solar processing equipment. Decentralized processing units at the farm level, such as solar dryers, horticulture processors, and grain mills, add value to agricultural produce and create rural employment opportunities. Government

schemes like PM SAMPADA Yojana offer subsidies to support such units among farmers, Self-Help Groups (SHGs), and Farmer Producer Organization (FPOs).

However, knowledge gaps, limited market linkages, and seasonal produce availability hinder full utilization of these schemes. Some companies are working to reduce these challenges by directly facilitating market linkages.

Deployment of solar hydroponic fodder units can be boosted through capacity building, awareness and new "fodder-as-a-service" business models. Solar hydroponic fodder (SHF) units provide a sustainable alternative to traditional fodder cultivation, with lower land, water, and electricity requirements. The potential market for SHF units in India exceeds 4.6 million, and suppliers are offering innovative "fodder-as-a-service" models to boost adoption. However, low awareness, unsold fodder risks, and lengthy sales conversion cycles pose challenges. Government support through schemes like the Fodder and Feed Development program can help, but additional capacity building and innovative business models are needed.

Off-grid solar productive use of renewable energy (PURE) products can benefit 35 million farmers, boosting their incomes by 20-40%*

New business model and financing innovations can scale access to PURE technologies. To accelerate the adoption of PURE products, innovative business models and financing approaches are crucial. Some business and service models including pay-per-use services, leveraging existing agri-retail networks, anchor-based financing, first-loss default guarantee funds, and carbon financing are emerging. Key players along the PURE value chain in aggregation, operation, financing, and facilitation of PURE are leading the way with innovative business models, addressing awareness gaps, and improving product accessibility through local franchisees and partnerships with Original Equipment Manufacturers (OEMs).

Multi-stakeholder collaboration is needed to create a long-term, sustainable ecosystem. Given the complexity of the challenges hindering the PURE sector, a multi-stakeholder approach is needed. For example, collaboration between the agriculture and energy sectors, and between the private and public sectors. If each plays a role in addressing relevant bottlenecks and issues, the potential of the industry can be rapidly amplified.

Enhancing the PURE policy framework can strengthen the foundations needed to boost agricultural outputs in rural India. The policy framework requires improvement to support PURE adoption. This report recommends setting up a PURE task force with end-user representation, mapping demand through a bottom-up approach, introducing quality standards, and establishing an integrated PURE policy. To stimulate demand, awareness campaigns, pilot demonstrations, and stakeholder outreach programs in both rural and urban areas are suggested. It is also recommended that the PURE industry needs to adopt global/Verasol's quality standards** and newly introduced GOGLA's consumer protection code to ensure quality and follow best practices. Collaborative efforts across sectors and continuous innovation are key to building a sustainable and scalable PURE ecosystem in India.

* Decentralised Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)

** Currently, VeraSol has established quality standards for the following products: walk-in cold rooms, egg incubators, electric pressure cookers, TVs, fans, refrigerators, and solar water pumps.

About this Research

1. About this Research

The 'Productive Use of Renewable Energy (PURE) in the Agriculture Value Chain: India Market Assessment' provides an in-depth analysis of the potential, challenges, and opportunities for the growth of PURE applications in India.

What is PURE?

Within this report, the term PURE focusses on distributed appliances powered by solar which support livelihoods. There are wide applications for PURE technologies, including the provision of energy and energy service for commercial enterprises, shops, and restaurants (see Table 1).

However, this report will focus on the use of PURE in the agricultural sector given its prominence and popularity in this sector within in India. The agricultural value chains studied include the dairy, fish, fruits and vegetables, and meat value chains. In particular, the study will investigate PURE products used for solar water pumping, solar powered food processing, solar powered cooling, and solar based animal feed production (see Table 2, Section 2)[1].

Report Objectives

The report aims to inform policymakers, practitioners, investors, and start-ups on the status and potential of using distributed solar energy to power agriculture and agricultural equipment in India. It does this by sharing:

- analysis of PURE products and companies in the market,
- analysis of the demand, supply, and anticipated trends in productive use of solar energy,
- a review of current PURE business models,
- a review of the enabling environment, including policies, programmes, and plans.

Methodology

To develop this report, valuable information regarding the productive use of solar energy was gathered through desk research, stakeholder mapping and key informant interviews. Consultations were held with relevant stakeholders including PURE suppliers, financing institutions, industry associations, government agencies and Non-Governmental Organisations (NGOs).

a. **Desk Review:** Several key reports, strategic documents, policies, and legislative frameworks were analyzed. A list of the documents reviewed is provided in Annexure 2.

b. **Stakeholder Mapping:** Through desk research and informant interviews, the research identified the key actors involved in the productive use of distributed solar energy in India. The list of the stakeholders consulted is provided in Annexure 1.

c. **Data Collection Tools:** To support this data collection, Informant Interview Guides were developed and implemented for the different stakeholder groups.

Table 1: List of PURE products

Application sector		PURE products
Agriculture and Allied sectors	Agriculture	Animal Repeller, Portable Lights, Irrigation Pumps, Pruner, Sprayer, Chaff Cutter, Paddy Thresher, Grain Mills, De-seeder & Huller, Grinder, Cold storage
	Animal Husbandry	Egg Incubators, Hydroponic Fodder Generation Units, Milking Machine, Milk Chillers, Milk Testing and Weighing
	Food processing	Solar Dryers, Flour Mixing, Roti Rolling Machine, Snack Making Machine, Oil Extractor, Sugarcane Juicer, Butter Churner, Wet Grinder, Horticulture Processor
	All	Lighting and Communications Devices
Other Micro, Small and Medium Enterprises	Textile	Cotton Picker, Ginning Machine, Charka, Looms, Yarn Winding, Silk Reeling, Silk Spinning, Sewing Machine
	Blacksmith	Fan Blower, Power Hammer, Angle Grinder
	Carpentry	Side Planer, Power Drill, Wood Lathe Machine
	Pottery	Pottery Wheel, Blunger and Pugmill
	Cottage industry	Spinning, Polisher, Cotton Wick Making
	Service and retail	Refrigerators, Air Compressors, Integrated Energy Centers
	All	Lighting and Communications Devices

1 These products have been shortlisted for the study based on their prominence in the broader PURE sector including market share, market potential, various scales of implementation and other key factors such as technology maturity, policy support, and affordability for end-users.

Overview of PURE in India

2. Overview of PURE in India

Context

While 100% of Indian households have access to electricity[2], the reliability of the grid supply remains a concern. According to the India Residential Energy Survey (IRES), 76% of households experience unforeseen interruptions, with two-thirds of households encountering outages at least once daily[3]. Rural areas are particularly affected.

In developing economies, distributed renewable energy (DRE) has emerged as a transformative driver in tackling energy poverty and enhancing energy access. Off-grid and remote communities are now experiencing the benefits of independent renewable energy generation-based appliances such as solar lighting, cooling, irrigation, and processing systems. These systems deliver clean electricity and electricity services to households, businesses and farms, alongside vital institutions such as schools and healthcare facilities. In doing so, these technologies are helping to improve socio-economic impacts by reducing poverty, enabling green growth, improving welfare, and creating clean energy jobs.

The Government of India has made significant strides in fostering solar adoption across the nation, championing initiatives such as the National Solar Mission. This initiative stands as a significant contribution by India to the global fight against climate change. This program promoting climate-smart technologies has catalyzed a remarkable surge in solar usage while concurrently driving down costs. As a result, the expense of solar modules has plummeted by a staggering 85% between 2010 and 2022[4], rendering them an increasingly accessible and viable alternative to traditional grid power sources.

Consequently, individuals, businesses, and communities are increasingly embracing on-site DRE solutions. By investing in these decentralized energy solutions, they aim to fulfill their electricity requirements while lessening reliance on centralized grid systems. In 2021, 179 million people gained access to electricity from DRE solutions — up from 35 million in 2012, to meet diverse energy needs for residential, institutional, and productive uses[5].

While solar lighting systems and efficient appliances such as fans, TVs and radios have been sold at scale for many years in India, the industry has more recently seen the emergence of a powerful new sub-sector focused on unlocking income generation and livelihoods. In particular, solar pumps and irrigation systems, cold storage, agri-processing and food processing equipment are providing significant impact and potential for enhancing agricultural production and preservation.

PURE products and impact

Given the vital role of agriculture in the Indian economy and the prevalent issue of unreliable energy access in rural agricultural communities, the adoption of PURE products presents a promising opportunity to enhance the livelihoods of those engaged in agriculture.

Solar irrigation: emerges as a well-established application, revolutionizing water accessibility, facilitating multiple cropping cycles, and substantially augmenting income potential—up to 50%[7].

Food processing: holds immense promise for extending shelf life and generating value-added opportunities, ultimately improving the farmers' incomes.

Agricultural equipment: the use of products like chaff cutters, paddy threshers, grain mills, de-seeders and hullers can also reduce drudgery within agriculture and improve productivity. Solar-based hydroponic fodder units, egg incubators represent yet another avenue for amplifying yields and fostering agricultural sustainability.

Cold storage and refrigeration: cooling technologies play pivotal roles at every stage of the agricultural value chain, extending shelf life, minimizing losses, and upholding crop and

2 100% Village Electrification Achieved in India, PIB (2022)
3 State of Electricity Access in India: Insights from the India Residential Energy consumption Survey (IRES), CEEW (2020)
4 Renewable Power Generation Costs, IRENA (2022)
5 Decentralised Renewable Energy must be at the centre of just and inclusive global energy transitions: Secretary, New & Renewable Energy, PIB (2023)
6 India Economic Survey 2022-23
7 Evaluation and Impact Assessment of Solar Irrigation Pumps - A deep dive in Haryana & Chhattisgarh, ICAI (2022)

fish quality. Enhancing access to cold storage facilities could effectively mitigate spoilage and post-harvest losses, which currently stand at around 14% in developing nations.

PURE Opportunity

To explore this opportunity, this report will focus on several key PURE technologies as noted in Table 2. Table 2 also profiles the stage of technology market maturity, the number of units of each technology installed in India, their market potential and whether or not there are existing government support schemes to accelerate their adoption.

Collectively the PURE products shortlisted for the study, including high-capacity pumps, micro pumps, dryers, grain milling, small horticulture processors, cold storages, small refrigerator/ deep freezers, bulk milk chillers and vertical fodder units have the potential to impact 35 million livelihoods. In addition, there is a revenue opportunity worth USD 46 billion for enterprises deploying and commercializing such products[8].

Recognizing the potential, the Government of India has initiated steps to promote PURE appliances. The Ministry of New and Renewable Energy (MNRE) has developed a draft policy aimed at fostering the adoption of PURE technologies. This policy focuses on several key areas: demand assessment, promotion of research and development, raising awareness, providing financial support, and facilitating pilot deployments.

Table 2: Overview of PURE products explored in this study

Application	PURE product	Market maturity	Installed units as of 2023	Addressable market (no. of units) as of 2023[9]	Existing Government Support
Solar water pumping	High-capacity pump (3-10 hp)	Commercial market	520,000	8,195,269	Exist
	Micro/ sub-hp pumps (including portable pumps) (<1 hp)	Near-to-market	1,500	3,425,032	None
Solar powered food processing	Solar powered grain - milling machine	Emerging	100	946,684	To an extent
	Solar powered small horticulture processor	Emerging	600	546,718	To an extent
	Solar dryer	Near-to-market	8,000	1,680,316	None
Solar powered cooling	Small refrigerator / deep freezer	Near-to-market	500	1,232,368	None
	Cold storage (Walk-in cold rooms)	Near-to-market	350	141,984	To an extent
	Bulk milk chiller	Emerging	50	90,224	To an extent
Solar-based animal feed production	Vertical Hydroponic Fodder Grow Unit	Emerging	210	3,379,510	To an extent

8 Decentralised Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)
9 Decentralized Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)

Case Study:

Policy Framework for developing and promoting Decentralized Renewable Energy Livelihood Applications by MNRE

The Ministry of New and Renewable Energy (MNRE), Government of India, has drafted a comprehensive policy framework to create an enabling ecosystem for widespread adoption of DRE livelihood applications (or PURE) across the country.

PURE Products Covered:

The policy covers a wide range of PURE products used directly for earning livelihoods such as solar dryers, cold storages/chillers, rice mills, textile machinery (silk reeling, spinning, weaving looms, solar charkha), food processing units, irrigation pumps, fodder stations and more. It also includes applications operating in hybrid mode with grid power.

Key Interventions Proposed:

a. Demand Assessment - Mapping potential for deploying PURE products across sectors/ regions
b. R&D and Standardization - Supporting innovation, technology transfer, setting standards
c. Piloting and Upscaling - Facilitating pilots, incubation support, monitoring platform
d. Access to Finance - Developing financing facilities, engaging banks, end-user finance models
e. Skill Development - Training programs, integrating into curricula of industrial training
f. Public Awareness - Digital catalogue, consumer campaigns, demonstrations
g. Convergence with Schemes - Coordinating with other ministries' programs

Institutional Mechanism:

An inter-ministerial Steering Committee chaired by MNRE Secretary with representations from 13 ministries/ departments is proposed to identify convergence opportunities, fill gaps, decide sectoral interventions, and recommend policy measures.

State implementation cells under the State Nodal Agencies (SNAs) will coordinate with state departments to provide technical support, mobilize resources, make plans and recommendations to the central committees.

The policy framework outlines a comprehensive strategy involving research, financing, capacity building, coordination, and awareness efforts to create sustainable livelihood opportunities through DRE applications.

Distribution and deployment of PURE products

The distribution of PURE products predominantly relies on "push" strategies rather than "pull" strategies[10], necessitating innovative business models for market penetration. Most PURE technologies are currently being sold on a cash basis, however some PURE companies are experimenting with innovative models like "pay-per-use". The majority of PURE product sales are also driven by government subsidies, Corporate Social Responsibility (CSR) funding, and donor support. This helps to kick start interest in these products but has not yet engendered long-term sustainability due to unclear volume and market visibility. Table 3 below shows a non-exhaustive list of PURE suppliers and their characteristics.

10 Push products are characterized by supply-driven dynamics where production leads demand, often requiring substantial efforts to create market awareness and stimulate adoption. This contrasts with pull products, which are driven by existing consumer demand.

Table 3: List of PURE Suppliers

Supplier	Stage of growth	Products offered	Business model	Clients
Shakti pumps	Successful (company has achieved breakeven point)	Solar water pumps (1 to 10 HP)	Outright purchase	• Government organizations • NGOs • Direct sales to end customers are not common – govt. act as intermediary
Kirloskar brothers				
TATA Power				
Khethworks	Start-up	Portable solar water pumps (<1 hp)	Outright purchase	• NGOs • Direct sales
Dhrambir food processing tech.	Start-up	Small horticulture processors	Outright purchase	• NGOs • Direct sales • Distributors
PLUSS Advanced tech.	Take-off stage	Solar dryers, Solar cold rooms	Outright purchase	• Direct sales • Distributors
Raheja Solar	Mature	Solar dryers	Outright purchase with produce buyback guarantee	• NGOs • Direct sales • Distributors
Inficold	Mature	Solar cold storages, Solar bulk milk chillers	Outright purchase	• NGOs • Direct sales to FPOs, Dairy cooperatives • Distributors
Ecozen	Successful	Solar cold rooms, Solar water pumps	Outright purchase	• Government organizations • NGOs • Direct sales to FPOs • Distributors
Temperate Technologies	Start-up	Solar cold rooms	Outright purchase	• Direct sales
DD Solar	Take-off stage	Solar refrigerators	Outright purchase	• NGOs • Direct sales • Distributors
Hydrogreens	Start-up	Solar hydroponics fodder unit	Outright purchase Pay-per-use	• NGOs • Direct sales • Distributors
AgriVijay	Take-off stage	Distribution of various solar based products	Distribution	• Distribution via agri retailers
Oorja Development Solutions	Start-up	Solar water pumps, Solar grain mill, Solar cold storage	Pay-per-use	• Services to end users
S4S technologies	Take-off stage	Solar dryer	Outright purchase with produce buyback guarantee	Direct sales to SHGs and other end users

Awareness and access

Although solar technology is gaining economic viability and there is an influx of new solar-based appliances into the market, many influential stakeholders have limited awareness of PURE products. This lack of awareness extends to financial institutions, resulting in a gap in consumer financing for consumers interested in purchasing PURE products due to low confidence among lenders. The distributed nature of these appliances also contributes to the limited presence of accessible after-sales services, adding to low utilization rates.

Despite the commercialization of some PURE products, such as solar water pumps, their deployment rates have remained low, primarily due to the significant upfront costs. These costs are between 2 and 13 times higher than conventional appliances, primarily due to the solar generation components required for PURE products, including solar panels, controllers, and batteries (wherever applicable).

The challenges and opportunities linked to scaling access to different PURE technologies are explored in Sections 3 – 6.

Image © pManifold

“Solar Water Pumping”

3. Solar Water Pumping

Solar Water Pumps (SWPs) have emerged as a sustainable solution to India's agricultural irrigation challenges, offering an alternative to traditional diesel or grid-powered pumps. With many rural areas lacking reliable access to electricity, solar pumps harness abundant sunlight to provide off-grid irrigation. They contribute to water conservation efforts, help farmers adapt to erratic rainfall patterns, and reduce dependency on fossil fuels. As India seeks sustainable development and agricultural modernization, SWPs are playing a pivotal role in enhancing productivity and promoting rural livelihoods.

SWPs are increasingly accessible to Indian farmers, regardless of their high installation costs. This is a result of the subsidies provided by the Government of India and various state governments to customers purchasing SWP. These subsidies can be substantial, between 60%-90% of the overall technology cost[11]. This support eases financial burdens for farmers interested in buying solar water pump alternatives. Access to SWPs empowers them to cultivate seasonal and high-value crops and reduces their dependence on the grid and fossil fuels for irrigation. Solar water pumps are also used in aquaculture and animal husbandry. An overview of use-cases by SWP size are included in Table 4.

Table 4: SWP Application areas

Application	Description	Sub - HP (< 1 HP) Optimal head: 10m Water output: ~ Up to 30,000 LPD	1-5 HP Optimal head: 30m Water output: ~ Up to 150,000 LPD	> 5 HP Optimal head: > 30m Water output: > 150,000 LPD
Irrigation	**Irrigation of farmland**	Up to 1 acre of land used for horticultural crop production can be irrigated Currently, these SWP are mostly used for drinking water applications	Around 5 acres of land can be irrigated 3-5 HP pumps are the most common pump types for irrigation	More than 5 acres of land can be irrigated
Fisheries / aquaculture	**Refilling of fish/ aquaculture ponds:** Water needs to be filled in avg. 2 days with pond Height ~1m	SWP can be used for small ponds (up to 0.15 acre)	SWP can be used for pond size up to 0.45 acre	SWP can be used for pond sizes of more than 0.45 acres
Animal husbandry	**Water for livestock feed:** Average water needs of 50 liters per animal per day	Up to 600 animals	Up to 3,000 animals	More than 3,000 animals

11 For example 90% subsidy provided in states like Chhattisgarh

Market Potential

There are approximately 100 million marginal land holdings in India of below one hectare in size[12]. In districts with a good availability of ground water and diesel pump usage, there is an immediate installation market potential for approximately 3 million micro/sub-hp solar water pumps[13]. Similarly, there are about 46 million large holdings above one hectare. Given the ground water availability, there is an immediate installation market potential of 8.2 million high-capacity solar water pumps[14]. These pumps can significantly enhance agricultural productivity by providing reliable access to water for irrigation.

According to data from the Land and Livestock Holdings Survey[15], there are around 0.4 million households that own livestock which require approximately 50 liters of water per animal per day and have good ground water resources. By harnessing solar energy to power water pumps, these households can ensure a consistent water supply, thereby optimizing livestock health and reducing the operational costs of their farms.

Solar pumps can also play a pivotal role in the aeration of aquaculture farms. Aeration ensures a continuous supply of oxygen crucial for maintaining optimal oxygen levels and regulating water temperature and quality in aquaculture farms. This function is particularly vital for sustaining aquatic environments and preventing the accumulation of pollutants detrimental to fish health.

The top three states with the highest potential of high-capacity pumps include Uttar Pradesh, Madhya Pradesh, and Gujarat. While for micro/sub-hp pumps, the states with highest potential include West Bengal, Bihar, and Kerala[16].

Supply and Business Model Analysis

The distribution of SWPs in the country largely happens through three major channels, direct sales, dealer, or partner networks, or via tenders including via NGOs through their livelihood initiatives. Direct sales are very low, with most sales are happening through the alternative channels.

Dealers who sell SWPs include local distributor partners of Original Equipment Manufacturers (OEMs), who often sell the pumps through various government tenders.

For example, under the KUSUM scheme, 40+ vendors are empaneled for supply of solar pumps. Among the empaneled agencies, 83% are Micro, Small & Medium Enterprises (MSMEs) and 17% are large corporates. The service portfolio of most of these vendors includes Solar Engineering, Procurement and Construction (EPC) and solar system integration. A small share of the agencies are the original pump manufacturers. Typically, these vendors offer sub-Hp/micro solar water pumps of less than 1 horsepower and high-capacity solar water pumps from 1-10 horsepower. The government tendering route is responsible for more than 50% of the SWPs installed in the country.

Another major channel for the distribution of SWPs in India is via NGOs. NGOs aggregate philanthropic capital and use it to facilitate the disbursement of SWPs to end-users. Companies in India such as Oorja Development Solutions are also operating SWP to provide irrigation services to customers.

Enabling Environment

Policies and programmes

Through ministries like the Ministry of New and Renewable Energy (MNRE) and the Ministry of Agriculture and Farmers Welfare, the Indian Government provides financial assistance to promote and incentivize the adoption of solar water pumps among farmers. This support not only encourages sustainable farming practices but also contributes to India's renewable energy goals, fostering a cleaner and more resilient energy future. Some of the current schemes that provide relief to farmers and MSMEs that purchase SWPs are PM-Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM), the Credit Guarantee Fund Scheme for Micro and Small Enterprises (CGS-I), the Marketing Assistance Scheme, and the Credit Guarantee Fund Scheme for NBFCs (CGS-II). A detailed overview of these policy frameworks for solar pumps is included in Table 5.

12 10th India Agriculture Census
13 Mainstreaming Micro Solar Pumps to Improve Incomes of Marginal Farmers, CEEW (2022)
14 Decentralised Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)
15 Situation Assessment of Agricultural Households and Land and Livestock Holdings of Households in Rural India, NSS (2019)
16 Decentralised Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)

Table 5: Schemes supporting SWP

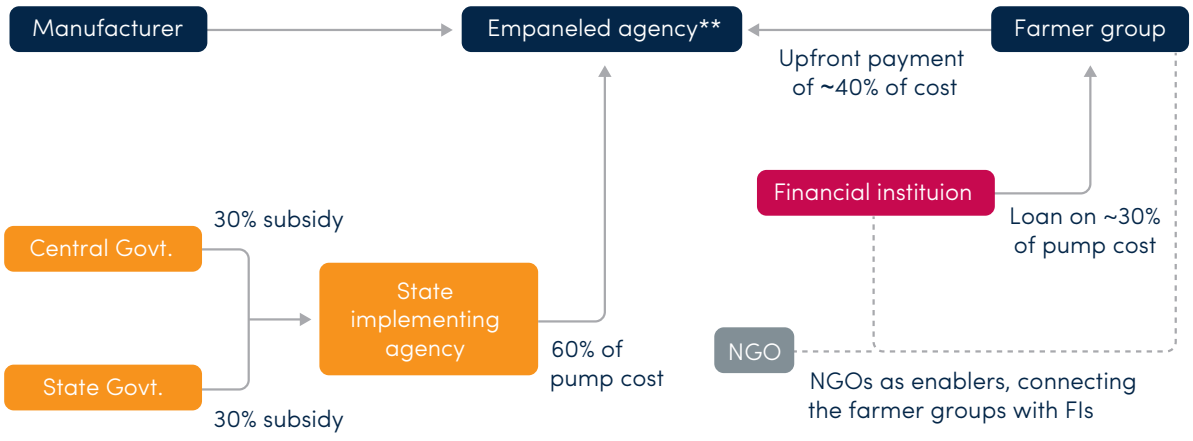
Schemes	Beneficiaries	Support
PM-Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM)	All farmers	Under component-B & component-C of PM-KUSUM, farmers are provided with a subsidy (central-30% & state-30%) to install off-grid and grid connected pumps of up to 7.5 HP. Under component-A, which focuses on Decentralized Ground/ Stilt Mounted Grid Connected Solar plants for water pumps, Procurement Based Incentive (PBI) is provided @ 6 cents/kWh or $8,000/MW/year, whichever is less for feeder solarization.
Credit Guarantee Fund Scheme for Micro and Small Enterprises (CGS-I)	All MSMEs	Covers credit facilities extended by a Member Lending Institution to a single eligible MSME borrower (manufacturer of pumps).
Marketing Assistance Scheme	All MSMEs	Provides marketing support to MSMEs by organizing national/ international technology expositions.
Credit Guarantee Fund Scheme for Non-Banking Financial Companies (CGS-II)	All NBFCs	The Credit Guarantee Scheme for Non-Banking Financial Companies (NBFCs) (CGS-II) provides a guarantee cover up to 75% for credit extended to micro and small enterprises by NBFC. This support mitigates the risk for lenders and encourages the provision of credit to underserved sectors, fostering financial inclusion, and supporting small business growth. Guarantees covers to all NBFCs which are standard and regular as per Reserve Bank of India (RBI) guidelines.

NGOs also play an important role in facilitating access to SWPs, especially by smallholder farmers. Due to their small land holdings, these farmers are unable to afford the minimum 3 horsepower capacity pumps required under the central government scheme, preventing them from benefiting from it. In such cases, NGOs, although not directly involved in the scheme's implementation, work closely with the end-users. They educate the farmers about the scheme's advantages, facilitate group formation, and assist them in accessing the scheme's benefits and loans, as illustrated in Table 6.

Business model innovations

Some companies are also exploring alternative ways to address the challenge of enabling access to solar water pumps by smallholder farmers. For example, Oorja Development Solution, have started water-as-a-service model where the company buys, deploys, and maintains the solar water pumps, while providing water on a pay per use basis to farmers. To maintain and operate the pumps, the company trains young people from the local community. Through this business model, the company can both increase access to water via SWPs and create employment opportunities for local youth.

Table 6: NGO enabled pathway of facilitating SWPs to smallholder farmers



Case Study:

Oorja Development Solutions: The 'pay-per-use' business model for solar irrigation

The pay-per-use service model is gaining traction in India's PURE sector, with companies striving to extend the benefits of PURE products to farming communities. This service model is particularly beneficial for low-income and marginal farmers, enabling them to access solar-based irrigation which would otherwise be financially out of reach, even with existing schemes. One notable example is the farming as-a-service model pioneered by Oorja Development Solutions.

Oorja has introduced three clean energy services: water for irrigation, milling of grains, and cold storage for horticultural produce. Each service operates on a pay-per-use basis, eliminating upfront technology costs for consumers. The on-farm irrigation solution offers a community solar irrigation service, providing on-demand water year-round to groups of 15 to 20 small farmers per pump. Oorja handles site identification, demand profiling, farmer group formation, system design and installation, and operates primarily in underserved, off-grid, or severely under-electrified regions. The company currently focusses on districts in Uttar Pradesh and Bihar. This community-based approach allows nearby farmers to access services without upfront costs, at tariffs 20 percent cheaper than diesel power. Currently the installed assets include 130 solar pumps, 15 solar mills, and 3 cold storages.

While Oorja manages day-to-day operations and maintenance, the company also provides technical and operational training to local technicians and pump operators, partnering with NGOs to foster community engagement. They employ and train local community members as pump operators, solar technicians, and sales and service agents.

To enhance the utilization of solar energy, Oorja has integrated milling solutions with solar pumps, offering affordable milling services for farming communities. Additionally, the company is developing proprietary technology for remote monitoring and control of asset performance, integrating customer and impact data, facilitating digital payments, and improving customer service efficiency. Through these interventions the company is aiming to deploy about 1,000 projects by 2026.

Key challenges

Although government initiatives to accelerate access to SWP are aimed at improving affordability by end-users, there are gaps in implementation. Implementation of initiatives varies across regions; however, several challenges are common**.** These include lengthy application verification processes, delays in payments to empaneled agencies, and inadequate fulfillment of demand due to limitations in state allocations. The current process of farmers applying for SWPs through state portals is often cumbersome and time-consuming. This prolonged application process is frequently followed by delayed payments to empaneled agencies, resulting in cash flow issues for vendors. In certain cases, the allocations from the state fail to meet the demand for pumps among farmers, thereby impeding the growth of SWP adoption. This situation is primarily attributed to insufficient budget allocations at the state level for SWPs.

Absence of subsidy for sub-hp micro pumps. The current scheme for SWPs only includes subsidies for pumps between 3-7 horsepower. However, according to the latest agriculture census[17], 70% of farmers in country are marginal farmers with small land holding of less than 2.5 acres. These farmers cannot benefit from the current scheme.

Access to finance for farmers. Farmers face challenges in getting loans to support the upfront cost required to purchase an SWP. This challenge arises due to low confidence by financial institutions around the viability of consumer finance for SWPs. Many banks also hesitate to accept farmland as collateral, fearing it may already be pledged as collateral for crop loans.

Underutilization of deployed assets. The PV-solar component of an SWP typically accounts for most of the cost. However, due to the seasonal or intermittent usage of the pumps, the power generated from solar energy is often underutilized, leading to extended return on investment periods. While the Ministry of New and Renewable Energy (MNRE) has introduced the 'Universal Solar Pump Controller', enabling end-users to connect other productive use loads to their PV-panel, adoption and awareness among users remain low.

17 10th India Agriculture Census

“Solar based cooling”

4. Solar based cooling

Addressing food loss and waste is an essential pillar of agricultural sustainability. India annually loses approximately 74 million tonnes of food[18], equal to 10% of the total food grain and horticulture production for the year 2022-23. India's staggering losses contribute to roughly 8% of all global food waste[19].

A significant factor contributing to this food loss waste in agriculture is the lack of adequate controlled environment storage facilities, particularly in rural India. This is especially true for perishables such as fresh fruits and vegetables, milk, and fish. These perishable need to be stored in a controlled environment with specific temperature and humidity levels to improve their shelf life. In this context, solar based cooling solutions can improve the shelf life of perishables and lead to reduction in wastage and improved income for the farmers.

Cold storages

Cold storage facilities help preserve perishable goods such as fruits, vegetables, and fish. They play a crucial role in extending the shelf life of these products, enabling their exportation over long distances. Bulk cold storage exists in the country for fruits and vegetables, these stores have large capacity and can be used for long term storage. However, a significant gap exists in first mile infrastructure like farm side storages which are comparatively small cold storages with 5-10 MT capacity. Here, the solar based cold storages will be an ideal solution for extending the shelf life and improving the income of farmers.

Bulk milk chillers

Bulk milk chillers play a crucial role in maintaining the quality of milk. The temperature of fresh milk is around 38°C but needs to be brought down to around 4°C within three to five hours to protect it from spoilage. To avoid spoilage, the bulk milk chiller (BMC) is the most critical component. Given the remoteness of many milk collection centres, solar powered milk chillers with thermal energy storage can help to provide reliable and affordable cooling solutions.

Small refrigerators

Refrigerators are specifically engineered to provide cooling for small-scale applications with limited storage capacity. The solar based small refrigeration or freezer units help customers to extend the life of perishable produce at the farm level such as for fruit pulp, fish, dairy products, etc.

Market Potential

As per the National Sample Survey Office's (NSSO) data on the Unincorporated Non-Agricultural Enterprises[20], approximately 143,053 microenterprises are involved in sectors such as refrigerated warehousing (cold storage) and the wholesale of fruits and vegetables, meat, fish, and eggs. However, around a thousand of these microenterprises encounter erratic electricity supply, leading to challenges in temperature control and remote monitoring[21]. The enterprises facing these challenges provide a key potential market for solar based cold storage solutions. The top three states with the highest potential are West Bengal, Tamil Nadu and Bihar.

Approximately 97,000 microenterprises are involved in the raw milk and dairy product value chains. Among these microenterprises 7,220 reportedly face challenges related to erratic electricity supply, leading to disruptions in their operations[22]. The adoption of solar based bulk milk chillers can mitigate these disruptions and contribute to increased productivity and efficiency in dairy processing. The top three states with the highest potential are Uttar Pradesh, Rajasthan and Madya Pradesh.

Approximately 6.8 million microenterprises are engaged in a range of other sectors where cold storage can boost productivity and income, including the manufacturing of dairy products (such as cream, butter, cheese, curd, ghee, and khoya), restaurants, bars, retail sales (including bakery products and beverages), and others[23]. Among these microenterprises, 196,533 reportedly encounter challenges such as unreliable grid supply and increasing electricity unit prices, underscoring the potential suitability

18 MoS Shobha Karandlaje inaugurates International Workshop on Food Loss and Waste Prevention in South Asian Region at New Delhi today, PIB (2023)
19 International Workshop on Food Loss and Waste Prevention in South Asian Region, ICAR (2023)
20 Unincorporated Non-agricultural Enterprises (excluding construction), 73rd round, NSSO (2018)
21 Decentralised Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)
22 Decentralised Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)
23 Unincorporated Non-agricultural Enterprises (excluding construction), 73rd round, NSSO (2018)

of solar refrigerators as a viable solution[24]. The top three states with the highest potential to benefit from cold storage solutions are Uttar Pradesh, Rajasthan and Madya Pradesh.

Approximately 6.8 million microenterprises are engaged in a range of other sectors where cold storage can boost productivity and income*

Supply and Business Model Analysis

Solar-based cooling represents a relatively new product category when compared to solar water pumps. The sub-sector includes a limited number of companies, primarily start-ups. While solar-based cold storage and refrigeration solutions are nearing market maturity, experiencing growing sales and attracting new market entrants, bulk milk chillers are still emerging, with initial sales only among early adopters. The deployment of these solar-based cooling solutions is largely facilitated by government subsidies or funding from development partners.

Cold storages are primarily owned by Farmer Producer Organizations (FPOs), while bulk milk chillers are predominantly owned by dairy cooperatives. While most cold storages are deployed under an own-to-use model, there are few pay-per-use deployments in the country, such as those established by Oorja Development Solutions. Solar refrigerators, meanwhile, are typically individually owned and utilized in grocery stores, fish vending and dairy businesses.

Enabling Environment

Unlike solar water pumps, solar based cooling solutions have not yet gained widespread recognition or adoption among farmers. This is due to factors including customer skepticism and lack of awareness or knowledge. As a result, farmers remain hesitant to invest in these systems, despite their potential to significantly enhance storage capabilities and mitigate post-harvest losses.

To foster greater adoption of solar based cooling, the Government of India is taking proactive measures. Solar cooling initiatives aim to assist farmers and support PURE companies to scale up their products for broader commercialization.

24 Decentralised Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)

* Unincorporated Non-agricultural Enterprises (excluding construction), 73rd round, NSSO (2018

Case Study:

Inficold: Solar based chilling in the dairy value chain

Milk production occurs at approximately 38°C, requiring rapid cooling to 4°C within three hours to prevent spoilage as it progresses through the supply chain. Currently, Indian cooperatives employ traditional bulk milk coolers, which are slower in cooling and sometimes rely on diesel generators due to unreliable grid energy. To address these challenges, companies are introducing solar-based cooling solutions for instant milk chilling. This faster cooling process not only reduces the risk of spoilage but also enhances milk quality, decreases energy demands on existing chillers, diminishes carbon emissions, and boosts profits.

Inficold has successfully implemented such a solution in dairy cooperatives across India, exemplified by the solar instant milk chiller at Kamdhenu milk cooperative.[25] This system has a 3,000 LPD milk chilling capacity, powered by 8 kWp of solar panels. It efficiently lowers milk temperature from 35°C to 10°C without reliance on electricity. Subsequently, the chilled milk is transferred to traditional bulk milk coolers, typically powered by grid electricity or diesel generators, for further cooling to 4°C. The solar instant milk chiller seamlessly transitions to grid supply during non-solar hours, further minimizing diesel generator usage.

The installation of the instant milk chiller has increased the cooperative's milk cooling capacity. With faster milk cooling and reduced spoilage risks, the cooperative has expanded its reach to additional villages within its catchment area, underscoring the transformative impact of solar-based cooling solutions on dairy operations in India.

25 How can increased access to solar milk chillers improve efficiency and smallholder incomes in the dairy value chain?, Shell Foundation (2022)

Cold storage

Schemes like the Mission for Integrated Development of Horticulture offer substantial credit-linked subsidies for customers purchasing solar cooling systems, ranging from 35% to 50%. The Infrastructure Fund provided by the National Bank for Agriculture and Rural Development (NABARD) meanwhile offers low-interest loans at rates between 9.25% to 10% for cold storage acquisitions by farmers. These initiatives play a vital role in incentivizing the adoption of cold storage solutions in rural India. By significantly reducing the financial burden associated with purchasing cold storage facilities, they empower farmers to invest in infrastructure that enhances their capacity to preserve agricultural produce effectively.

A specific scheme aimed at creating awareness of solar cold storage is the Agricultural Produce and Livestock Marketing (Promotion & Facilitation) Act (APLM) enacted in 2017. This legislation plays a crucial role in facilitating deployments of cold storage facilities within marketplaces through FPOs. The act aims to facilitate storage services and foster increased utilization of cold storage facilities across rural communities through Warehouse Receipt Financing (WRF)[26]. Consequently, it helps mitigate post-harvest losses and enhances overall agricultural productivity.

Other such initiatives are Atma Nirbhar Bharat-Agriculture and the Agriculture Export Policy which are geared towards incentivizing and facilitating the widespread implementation of solar cold storage solutions across agricultural communities.

Bulk milk chiller

To meet the surging demand for milk in India, and overcome the operational challenges faced by aging milk processing plants established during Operation Flood[27], the Ministry of Animal Husbandry and Dairying has launched a series of initiatives. These efforts are aimed at modernizing milk processing infrastructure by implementing various strategies, including enhancing energy efficiency, and integrating renewable energy solutions in collection center infrastructure such as bulk milk chillers.

Key initiatives in this endeavor include the National Program for Dairy Development (NPDD) and the Dairy Processing and Infrastructure Development Fund (DIDF). Through NPDD, funding is allocated for establishing primary milk chilling facilities by dairy cooperatives, with designated end implementing agencies overseeing the execution. DIDF extends loan assistance to these implementing agencies through National Dairy Development Board (NDDB) & National Bank for Agriculture and Rural Development (NABARD).

Beneficiaries under these schemes include a diverse array of stakeholders ranging from State Dairy Federations, District Milk Unions, and Milk Producers Companies to Multi-State Cooperatives, Milk Producer Companies (MPCs), Farmers Producer Organizations (FPOs), Self-Help Groups (SHGs), and NDDB subsidiaries nationwide, who are Eligible End Borrowers (EEBs)[28].

Technical specifications for bulk milk chillers are outlined for all NDDB programs, encompassing critical aspects such as cooling requirements for the milk collection cycle and the design parameters for condensing units. This ensures standardized and efficient milk processing practices across the country, contributing to the overall enhancement of the dairy industry's efficiency and sustainability[29].

Key Challenges

Gaps in the product market fit. In the current market, most available cold storage units are single-chamber designs with a temperature range of 4 - 15°C. These units can only accommodate a single type of seasonal produce, thereby limiting their utilization. Additionally, there is a demand for smaller cold storage units at the farm level, a product category currently absent from the offerings of existing companies.

Gaps in enforcement of quality and performance standards for solar based cooling appliances. The Department of Horticulture categorized cold storage units into seven groups based on factors such as humidity, ethylene sensitivity, and susceptibility to chilling injury[30]. However, many end consumers report that their cold storage does not keep produce fresh.

26 Warehouse Receipt Financing (WRF) is a method where farmers can store their produce in a certified warehouse and receive a receipt, which can be used as collateral to obtain loans from financial institutions. This system benefits farmers by allowing them to access credit without selling their produce immediately, thus enabling them to time the market better and potentially secure higher prices while smoothing out their cash flow.

27 Operation Flood, launched on January 13, 1970, was the world's largest dairy development programme and a landmark project of India's National Dairy Development Board. It transformed India from a milk-deficient nation into the world's largest milk producer.

28 Eligible End Borrowers (EEBs) are the entities with making profit and is having positive net worth.

29 Direct Expansion Type Bulk Milk Cooling System Specifications, NDDB Anand (2010)

30 Technical Standards and Protocols for Cold Chain in India, Cold Chain Development Centre (2010)

The lack of standardized specifications and quality standards in existing schemes, and the absence of post-installation monitoring further compound this issue. Consequently, many end-users have lower confidence in the reliability and performance of cold storage units.

Low demand, due to high upfront costs. The current low demand for solar-based cooling solutions stems from their elevated costs, deterring widespread adoption. Furthermore, the intricate technology involved often leads companies to contend with narrow profit margins. Although scaling up production has the potential to enhance profitability by optimizing economies of scale, the prevailing low demand undermines business viability in this sector, discouraging companies from active participation.

Lack of robust remote monitoring solutions. The distributed nature of these systems poses a challenge for implementing robust monitoring, particularly for solar refrigerator units. The lack of robust monitoring mechanisms hinders companies from exploring innovative financing models, such as PAYGO[31], which could enhance affordability for end-users. Remote monitoring also assists the companies in monitoring the performance of the appliance and predicting when they need maintenance.

Low awareness among the end-users. Many milk cooperatives in India continue to utilize traditional bulk milk coolers for chilling milk, frequently relying on diesel generators due to the unreliable grid energy supply. However, many remain unaware of the economic and environmental benefits provided by solar-powered systems for milk cooling. This lack of awareness perpetuates the dependence on diesel generators in various regions of the country.[32]

Image © pManifold

31 PAYGo, or Pay-As-You-Go, is a financing model used to provide off-grid solar energy solutions. It allows consumers to pay for solar products in small, regular installments, making it affordable for low-income households. This model leverages mobile payment technology and enables users to unlock and use the solar system through periodic payments, which can be daily, weekly, or monthly. Once the total cost is paid off, the customer owns the system outright.

32 How can increased access to solar milk chillers improve efficiency and smallholder incomes in the dairy value chain?, Shell Foundation (2022)

“Solar Based Food Processing”

5. Solar Based Food Processing

Processing plays a pivotal role in the agri-food value chain, wielding considerable influence over the capacity of food systems to add value, mitigate post-harvest losses, and bolster socio-economic benefits for farming communities. Across India, most agricultural produce such as vegetables, fruits, grains, pulses, flowers, and herbs have a potential to undergo processing to extract pulp, juices, etc. Today, only about 10% of the total agriculture output is processed. The Indian Government aims to expands it to 25% by 2025[33].

Currently the processing units are dispersed and far from farm locations. Much of the produce therefore traverses lengthy supply chains, often taking a long time to reach processing facilities. This extended time between harvest and processing increases the risk of damage and spoilage, particularly for perishable items. Decentralized processing units at the farm level offer a solution to mitigate such losses, enhance the value of produce, reduce horticultural losses, and create new livelihood opportunities. Decentralized processing that can be done at farm gate includes drying, milling and processing of horticultural produce like vegetables, fruits, and flowers.

Solar dryers

Dried products extend storage life through dehydration, enabling farmers to command higher prices during off seasons. Traditional sun drying methods are slow and prone to contamination. Engineered dryers can help to reduce spoilage. However, electricity is often inaccessible in rural India. Solar dryers provide a practical solution for dehydration in such areas, suitable for drying a range of agricultural produce including coconut, green chili, peas, garlic, onions, leafy vegetables, grapes, and mangoes.

Small horticulture processors

Small horticulture processors (SHPs) also help in extending life and fetching higher prices through extraction of pulp, paste etc. These appliances not only assist in navigating market dynamics but also create income opportunities. In addition to jobs operating the machines, these jobs involve various associated steps such as procuring crops, primary processing like peeling, dicing, packaging and sales.

Solar grain milling

Grain milling is a common practice in the Indian agricultural value chain, with farmers traditionally relying on grid-connected electric mills. However, solar-based milling offers a compelling value proposition due to its reliability and affordability. This is especially true in remote areas with erratic electricity supply and where accessing existing mills is challenging due to the distance from demand centers.

Market Potential

Farmers, Farmer Produce Organizations (FPOs) and Self-Help Groups (SHGs) can be key beneficiaries of decentralized processing units. With approximately 75 million women that have organized into SHGs under the National Rural Livelihood Mission[34] and 10,000 FPOs established through the Small Farmers Agri-Business Consortium, there is good potential to expand the use of off-grid solar based food processing units.

Studies suggest the decentralized horticulture processing industry presents a substantial market opportunity of approximately 0.6 million solar horticulture processors, which would generate around 1.3 million livelihoods[35]. The top three states with highest potential are Uttar Pradesh, Bihar and West Bengal.

According to the National Sample Survey Office's (NSSO) 2018 data[36], almost a million microenterprises in India are engaged in milling grains such as wheat, rice, and dal. Among these microenterprises, almost a quarter reportedly encounter challenges due to unreliable grid supply and could be a potential audience for solar milling machines. The three states with the highest number of microenterprises focused on milling but which are challenged by unreliable grid access are Uttar Pradesh, Maharashtra and Madya Pradesh.

33 Food Processing Industry in India: Challenges and Potential, RBI Bulletin (2020)
34 National Rural Livelihood Mission, Ministry of Rural Development
35 Can Small Horticulture Processors Enhance Rural Incomes?, CEEW (2022)
36 Unincorporated Non-agricultural Enterprises (excluding construction), 73rd round, NSSO (2018)

Over 200,000 microenterprises are involved in drying produce with most of them using open sun-drying[37]. These enterprises can also benefit from the adoption of solar dryers. The states with the highest number of such microenterprises are Maharashtra, Andhra Pradesh and Madya Pradesh.

Supply and Business Model Analysis

Solar based food processing is a relatively new product category with few companies manufacturing these products. However, among these products, solar dryers are gaining popularity.

Solar dryers

The suppliers of solar dryers in India offering different technologies for the drying/ dehydration of food include Raheja Solar, Rudra Solar and S4S technologies. Convection dryers (natural and forced), conduction dryers and tunnel dryers are common types of dryers offered by these suppliers. Convection dryers (both natural and forced convection) and conduction dryers are cabinet type dryers with capacities ranging between 15-30 kg. Tunnel type dryers are used for large quantities of produce dehydration of more than 100 kg.

A key driver for increased adoption of solar dryers has been the facilitation of market linkage between customers processing food and purchasers, which has been aided by solar dryer suppliers. The business model adopted by some of these suppliers includes buy-back of the dried produce and selling it to existing Fast Moving Consumer Goods (FMCG) players. This creates demand, as well as a steady income for users of the dryers.

Small horticulture processors

Solar based horticulture processor suppliers are limited but include Dharambir Food Processing which offers SHPs for processing fruits, vegetables, and flowers of capacities around 10-120 liters.

Solar grain mill

Solar mill suppliers are also limited in India but include key players such as Ornate Solar and Confider. These companies focus on integrating milling solutions with solar water pumps, to maximize the utilization of solar panels for water pumping applications.

Case Study:

S4S Technologies: Market linkage for solar dryer users

A significant challenge faced by the food processing industry in India is the market linkage between farmers and centralized processing facilities of packaged food companies, a gap mirrored in solar-based processing initiatives. To address this issue, companies are implementing solutions that ensure the buy-back of processed produce, while simultaneously creating income-generation opportunities through sustainable processing infrastructure. One such solution is offered by S4S Technologies.

S4S Technologies operates as a decentralized agricultural processing platform, delivering shelf-stable, nutrition-rich, and convenient foods to industrial kitchens and packaged food companies. The company's approach involves replacing fresh supplies in industrial applications with produce from decentralized food processing units. S4S's model incorporates solar-powered decentralized food dehydration systems at the village level, complemented by centralized secondary processing units for grading, sorting, and packaging.

This model encompasses the deployment of solar dryers for dehydration at the farm level, along with training programs for local women to operate these dryers. Secondary processing and warehousing occur at centralized units, followed by marketing and distribution to industry clients. By identifying and training women as agri-entrepreneurs to operate the dryers, S4S not only facilitates sustainable drying solutions but also empowers women by providing avenues for income generation. This integrated approach not only bridges the gap between farmers and processing companies but also fosters economic empowerment within local communities.

37 Decentralised Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)

Enabling Environment

To strengthen the agro processing sector, the Ministry of Food Processing Industries of India introduced a scheme called Pradhan Mantri Kisan SAMPADA Yojana with an outlay of INR 4,600 crores. The umbrella scheme supports the growth of the food processing sector with various components focused on developing food parks, cold chain, food safety and quality assurance and supply chain connectivity, among others. Within this scheme, the Creation of Backward and Forward Linkages for processing industries focusses on plugging the gaps in supply chain in terms of availability of raw material (backward linkage) and linkages with the market (forward linkage). The scheme supports the decentralized processing of perishable produce by providing grants up to 50% for setting up processing or collection centers at the farm gate. The farmers can access the grants under this scheme to set up solar based food processing units at the farm gate.

To establish sufficient infrastructure for primary processing and to facilitate value addition through established post-harvest technologies, the Ministry of Micro, Small, and Medium Enterprises, under its post-harvest management program, provides support in the form of a 40% subsidy of the total cost of the technology/ project and a 100% grant-in-aid for purchase of machinery and contingency expenditure for farmers[38]. Self Help Group (SHG)/User Groups (UG) of farmers/ Cooperative Societies of Farmers/Non-Governmental Organizations (NGOs) can enter into a bilateral agreement with the ICAR for establishment of units under this program.

The National Bank for Agriculture and Rural Development (NABARD) has launched an initiative known as the Producers Organization Development Fund (PODF), starting with an initial corpus of USD 6.9 million. This fund is designed to support Producer Organizations (POs) across three critical areas: credit support, capacity building, and market linkage support. It also addresses the end-to-end requirements of producers, thereby ensuring sustainability and economic viability[39]. This could present an opportunity for POs to get support to purchase and run solar food processing machinery.

Table 6: Schemes supporting Solar based food processing

Schemes	Beneficiaries	Support
Pradhan Mantri Kisan SAMPADA Yojana by the Ministry of Food Processing Industries	Farmers, SHGs, FPOs, machine manufacturers	The maximum grant extended per project is USD 0.7 million (INR 5 crore)
Post-Harvest Technology and Management by Ministry of Micro, Small and Medium Enterprises	SHGs, cooperatives, farmers, user groups	Nature of assistance is a 100% grant-in-aid for purchase of machinery and contingency expenditure
Producers' Organization Development Fund (PODF) by National Bank for Agriculture and Rural Development	Producer companies, producers' cooperatives, registered farmer federations, macs (mutually aided cooperative society), industrial cooperative societies, other registered federations	Initial corpus of USD 6.9 million (INR 50 crore). The grant amount is capped at 20% of the loan amount
Pradhan Mantri Formalization of Micro Food Processing Enterprises Scheme (PMFME)	Individuals, FPOs, SHGs, NGOs, Cooperatives, SPV of micro food processing enterprises	Credit linked capital subsidy at 35% of the eligible project cost - maximum of Rs. 10.0 lakhs per unit for upgradation or setting up of new units. 50% financial grant for Branding and Marketing.

38 MSME Schemes, National Institute for Micro, Small and Medium Enterprises
39 NABARD website

Key Challenges

Knowledge gap amongst end-users of solar processing products on operation of product, marketing, inventory management, quality management and safety standards. End-users frequently encounter challenges when operating food processing equipment, leading to difficulties in achieving the required parameters like sugar acid ratio for the processed produce. This, in turn, creates gaps in the quality of the final product and reduces consumer interest.

Inability of users of the solar processing technologies to sell their processed produce. Although government initiatives have been promoting schemes for establishing backward and forward market linkages for processed horticulture produce, users of this equipment still feel the need for further improvements in market linkages, for example, the creation of distribution hubs for sorting, grading, and packaging of processed food.

Underutilization of assets due to seasonal cropping. The produce that undergoes processing is often seasonal resulting in underutilization of the solar processing appliances and a longer time until customers see a return on their investment. This also affects the income for staff involved in processing activities.

Image © pManifold

“Solar-Based Animal Feed Production”

6. Solar-Based Animal Feed Production

India is the largest milk-producing nation, contributing approximately 22% of the total global production. Traditionally, mammalian livestock are fed by grazing on open grasslands, a method that demands considerable time, patience, and human labor to oversee and protect the animals. Another traditional approach involves cultivating grass, commonly Napier grass, in states such as Uttar Pradesh, Haryana, Punjab, Bihar, Madhya Pradesh, Gujarat, and Andhra Pradesh, among others. However, Napier grass typically requires a minimum of 30 days to reach maturity and consumes significant farmland, water, and electricity resources during cultivation.

In contrast, Solar Hydroponic Fodder (SHF) units offer a more sustainable and efficient alternative. These systems require less space compared to traditional farmland due to both horizontal and vertical tray setups. Cultivated through hydroponic systems, they enable precise nutrient delivery, leading to accelerated growth rates. This approach reduces water usage by an impressive 70% compared to conventional methods.

Furthermore, SHF units harnessing solar energy to power the pumps conserve water resources and mitigate challenges associated with electricity consumption. By reducing reliance on conventional energy sources, these systems play a crucial role in curbing carbon emissions from energy production. The feed generated through the fodder units has also been specifically designed to reduce methane generation by cattle when compared to grazing. These fodder units therefore play a key role in fostering environmental sustainability within the livestock farming industry, offering a promising solution to address pressing challenges while ensuring long-term viability and resilience.

Market Potential

Over the past years, the dairy industry in India has experienced exponential growth, leading to increased income and economic growth for many families. Companies are now exploring the production of hygienic and nutritious milk products to establish Indian dairy brands on the global stage. Central to this endeavor is the provision of high-quality fodder to ensure the health and nutrition of livestock.

According to fodder deficit data from the Government of India (GOI), it's estimated that more than 4.6 million SHF units could be used across India, with the potential to benefit up to 16 million livestock farmers. Key states like Uttar Pradesh, Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Telangana, and Bihar collectively contribute over 80% of this potential[40].

Supply and Business Model Analysis

SHF unit suppliers in India are currently limited in number but include Hydrogreens and Auto Studio. Companies offer SHF units both as individual units and through a fodder-as-a-service model. Individual units typically have capacities ranging from 10-14 kg/day to 20-28 kg/day. Fodder-as-a-service is provided through central fodder stations, with capacities ranging from 100 kg to 10 tons of fodder per day. These stations are often located at milk collection centers, allowing farmers to conveniently collect fodder when they visit the center to supply milk. Users can opt for a subscription model where they pay a fixed amount for fodder every day, or a pay-per-use model where they buy fodder as needed.

Fodder cultivated through hydroponic systems enable precise nutrient delivery, leading to accelerated growth rates. This approach reduces water usage by an impressive 70% compared to conventional methods.

40 Enhancing India's milk and meat production: Is hydroponics green fodder the answer?, CEEW (2021)

Case Study:

Hydrogreens: Fodder-as-a-service

SHF units serve as a vital source of nutritious green fodder, naturally palatable, digestible, and available year-round for livestock. To alleviate the upfront capital costs for dairy farmers, Hydrogreens has introduced an innovative retail model for fodder distribution known as the fodder station.

At the core of this initiative is the Kambali unit, a fodder growing house designed to produce high-quality fodder and cultivate crops such as wheatgrass and mushrooms. A notable deployment of this model can be observed at Bahula dairy farm, supported by Urmul Seemant as a distribution partner, located in Bajju village, Rajasthan.

Hydrogreens established the fodder station at Bahula dairy cooperative, operated in collaboration with Urmul. Here, individual dairy farmers, women farmer SHGs, and FPOs engaged in livestock rearing purchase fodder directly from the station and subsequently sell their milk to Bahula dairy. The efficiency of Hydrogreens' system is evident in its relatively lower water usage, a critical advantage in regions like Bajju village which face water scarcity.

The abundance of high-quality fodder produced by Hydrogreens has led to a reduction in expenditure on concentrate feeds, while simultaneously increasing milk yields and fat content. This intervention has resulted in tangible benefits for users, including increased income from milk sales and reduced production costs per liter of milk.

Enabling environment

The Government of India (GOI) is committed to the comprehensive development of farmers and entrepreneurs interested in purchasing SHF units by offering support and training to state governments and dairy farmers. This includes providing soft loans to corporations and Farmer Producer Organizations (FPOs) engaged in dairy activities, particularly in rural areas. Subsidies are also provided for the establishment of fodder and feed-making units through initiatives such as the Fodder and Feed Development Scheme and supporting dairy cooperatives and FPOs involved in dairy activities, as facilitated by the Ministry of Agriculture and Farmer's Welfare (MAFD). An overview of these schemes is provided in Table 7.

Table 7: Schemes supporting SHFs

Schemes	Beneficiaries	Support
Fodder and Feed Development Scheme	Livestock farmers	Providing subsidies for fodder and feed making units and promoting improved variation of fodders
Dairy Entrepreneurship Development Scheme by Ministry of Fisheries, Animal Husbandry and Dairy (MFAD)	Livestock farmers, entrepreneurs, SHGs, dairy cooperatives, district milk unions	Allied businesses assisting commercially bankable projects with loans from commercial, cooperatives, urban and rural banks of up to 40 % of total outlay.
Supporting dairy cooperatives and farmer producer organizations engaged in dairy activities by MFAD	Livestock farmers	Providing soft loans for working capital to cooperatives and FPOs in dairy activities, and stable market access to dairy farmers
Quality Mark for Dairy and Dairy Products by National Dairy Development Board (NDDB), MFAD	Dairy cooperatives, dairy units of educational institutes or government	Units satisfying quality mark criteria will be allowed to use the logo on milk and milk product packaging
Animal Husbandry Infrastructure Development Fund	MSMEs, individual entrepreneurs, FPOs, private companies, Section 8 companies	Providing loans for up to 90% of the product cost

Key Challenges

Long lead time and sales conversion because of low awareness and trust in new SHF technologies. The farmers involved in conventional fodder generation practice often feel hesitant towards moving to new methods of producing the fodder. Creation of awareness among farmers takes time and effort which leads to slow cashflows for SHF suppliers.

Risk of unsold fodder and under subscription in the case of the fodder-as-a-service model. While the implementation of a large fodder station with a service model effectively tackles the hurdle of upfront costs for farmers, thereby enhancing the adoption of SHF units, the absence of a fixed number of buyers poses a risk of underutilization of assets for SHF station owners, particularly during seasons with good monsoon conditions where there is an abundance of available grass.

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“Opportunities for Suppliers and Financial Institutions”

7. Opportunities for Suppliers and Financial Institutions

The significant potential of PURE products in India presents a wealth of opportunities for various stakeholders throughout the value chain, including Original Equipment Manufacturers (OEMs), distributors, and financial institutions. These stakeholders must move beyond merely selling and financing products to establish an ecosystem that promotes sustained benefits and ensures that these technologies are affordable and accessible to target users. Innovative endeavors in this area are crucial for addressing existing challenges and driving the widespread adoption of PURE technologies nationwide. These innovations will help transition from reliance on government subsidies, Corporate Social Responsibility (CSR) funding, and donor support for product sales to a model of long-term sustainability in the sector.

Conventionally, the common business model among PURE stakeholders has been the cash sale of appliances with subsidies from government policies, donor support aiding end-consumers. Even with subsidies and support, the upfront cost of PURE technologies can be prohibitive.

However, several new innovative approaches are being pursued in the Indian PURE sector which aim to enhance access to PURE technologies, either individually by a single stakeholder or through collaborative efforts involving multiple stakeholders. These approaches could revolutionize the sector and promote long-term sustainability.

Innovation in Business Models

Pay-per-use business model

In the pay-per-use model, PURE enterprises offer services, including irrigation, cooling, food processing, and fodder, on a subscription or pay-per-use basis. This model addresses the challenge of upfront capital expenditure requirements for farmers and can improve adoption of the technologies. The model also addresses the challenge of farmers maintaining and servicing the PURE assets.

Pay-per-use services can be offered to the farmers at par with the cost of conventional technology. For PURE service providers, the payback period of about 4-5 years can be achieved for high capex, low utilization products like cold storage systems. A much shorter payback period can be achieved for products with comparatively low capex and higher utilization like solar water pumps and fodder units. By carefully selecting sites and identifying groups of farmers suitable for the services provided, solutions can be deployed at scale.

Distribution via agri-retailers

Another significant challenge hindering the adoption of PURE products among farmers is the gap in availability and accessibility. Establishing an effective distribution network for PURE products and enhancing their availability to end-users can significantly boost their adoption. Enterprises can leverage existing vendors of agricultural inputs, such as fertilizer distributors, or vendors of agricultural machinery at the village level. Additionally, agri-retailers can facilitate after-sales services, taking advantage of the proximity of the marketplace to the deployed assets. This approach not only enhances the credibility of the products but also strengthens the marketplace itself.

Innovation in Financing

Anchor based financing

Bankers exhibit caution when it comes to extending loans to farmers and other participants within the value chain due to various factors such as insufficient data, limited market linkages, high transactional costs associated with lending, and challenges in recovery. In this context, PURE product OEMs possessing a deep understanding of the value of their products can play a pivotal role by assuming an anchor position. By doing so, they can facilitate asset-backed financing solutions for end-users, thereby mitigating the apprehensions of lenders and promoting greater access to finance within the agricultural sector.

Case Study:

AgriVijay: Renewable Energy Marketplace

With approximately 80 Renewable Energy (RE) stores established, AgriVijay has leveraged existing rural retailers—local entrepreneurs with established businesses in hardware and pesticides—as franchisees, to develop a 'Renewable Energy Marketplace' catering to farmers and rural households. To become a franchisee, AgriVijay requires an investment of $300-480. It's partner retailers undergo thorough training so that they can educate farmers about the products and provide demonstrations, while also becoming equipped to handle basic maintenance tasks.

Through its innovative business model, AgriVijay effectively addresses several challenges associated with off-grid RE appliances, including:

- **Creating Awareness:** Proactively raising awareness among farmers about the products and their applications and ensuring they understand the benefits.
- **Improving Product Availability:** Ensuring a wide range of RE products are readily available, thereby meeting diverse needs and preferences of rural customers.
- **Improving Product Accessibility:** Making RE products easily accessible to rural communities, bridging the gap between demand and supply through localized distribution networks.
- **After-Sales Services:** Offering comprehensive after-sales services, including general maintenance and repairs. To facilitate this, AgriVijay has established local call centers staffed with multilingual agents, enabling farmers to report issues effortlessly.
- **Financing Solutions:** Collaborating with financing institutions to provide flexible financing options, making it easier for farmers to acquire RE products without significant upfront investment.

By addressing these critical aspects, AgriVijay not only facilitates the adoption of renewable energy solutions but also contributes to rural development and sustainability by empowering farmers and rural households with clean and reliable energy alternatives.

However, challenges persist, including ensuring quality installations, providing timely after-sales services, and onboarding local vendors. Streamlining these issues through continuous technician training and clear standard operating procedures (SOPs) for customer acquisition will enhance scalability for this model.

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Case Study:

Samunnati: Agri value chain financing through anchor institutions

Samunnati operates in the field of financial services, specializing in providing financial assistance and enhancing access to finance for underserved geographical areas and customer segments within the agricultural sector. Their primary focus involves offering or arranging loans and advances tailored to the specific needs of agricultural stakeholders.

Samunnati's innovative B2B2C financing model stands out as a key feature of their approach. Through this model, they effectively provide financial assistance to agricultural customers by collaborating with anchors. Traditionally, this model has been employed for various farm loans, with FPOs serving as the anchor. However, Samunnati has expanded this approach to encompass PURE products, involving distributors and original equipment manufacturers (OEMs) as anchors.

Samunnati with a total INR 1,000 crore plus portfolio, with around 50 crore of solar asset financing. B2B2C has about 5-10% share of the overall portfolio.

By leveraging this risk-sharing tool, Samunnati can offer loans at subsidized interest rates to end-users, thereby enhancing access to finance for agricultural stakeholders. This innovative approach promotes financial inclusion and facilitates the adoption of sustainable energy solutions in rural areas, contributing to overall socio-economic development.

Default guarantee fund

Banks often hesitate to extend finance to farmers due to the perceived low credibility of this demographic. First-loss default guarantee funds have emerged as a tool to facilitate high-risk loans across various sectors. These funds can be used as a risk sharing option to give Financial Institutions (FIs) the confidence in extending finance to the farmers. Such arrangements have been set up by the Ministry of MSMEs to increase lending for small businesses. Implementing a similar approach to facilitate finance for farmers seeking to procure PURE products would be instrumental in scaling up adoption.

Case Study:

Loss default guarantee fund by SwitchON

SwitchON Foundation has forged a strategic partnership with Punjab National Bank to drive the promotion of solar pumps. Under this collaboration, SwitchON Foundation will establish a First Loss Default Guarantee Fund, enabling Punjab National Bank to finance solar pumps for farmers. The primary objective of this fund is to facilitate the financing of solar pumps for small marginal farmers who may not have access to traditional banking services or collateral.

With the assurance provided by the guarantee fund, Punjab National Bank, a leading public sector bank, is extending a longer-than-usual payback period of 7 years. Moreover, this initiative offers small and marginal farmers the opportunity to access loans of up to 1.6 lakhs with zero down payment.

SwitchON collaborates closely with farming communities to provide education on the benefits and operation and maintenance of solar pumps. While previously partnering with RBL and Axis Bank to sanction loans for over 100 solar pumps. Notably, there have been zero Non-Performing Assets (NPAs) recorded to date, underscoring the success and reliability of SwitchON's initiatives in promoting solar pump adoption among farmers.

Carbon financing

The deployment of PURE technologies presents an opportunity for generating carbon credits, which can serve as an additional revenue stream for developers and OEMs.

Case Study:

Carbon financing through D-REC

D-RECs (Distributed Renewable Energy Certificates) are a globally recognized market instrument which aims to expediate the transition towards universal energy access. By leveraging innovative Measurement, Reporting, and Verification (MRV) technology, this instrument streamlines access to global environmental markets for distributed renewable energy projects. Despite the benefits offered by small-scale solar devices, the companies deploying them frequently encounter challenges in securing impact finance necessary to advance their solutions.

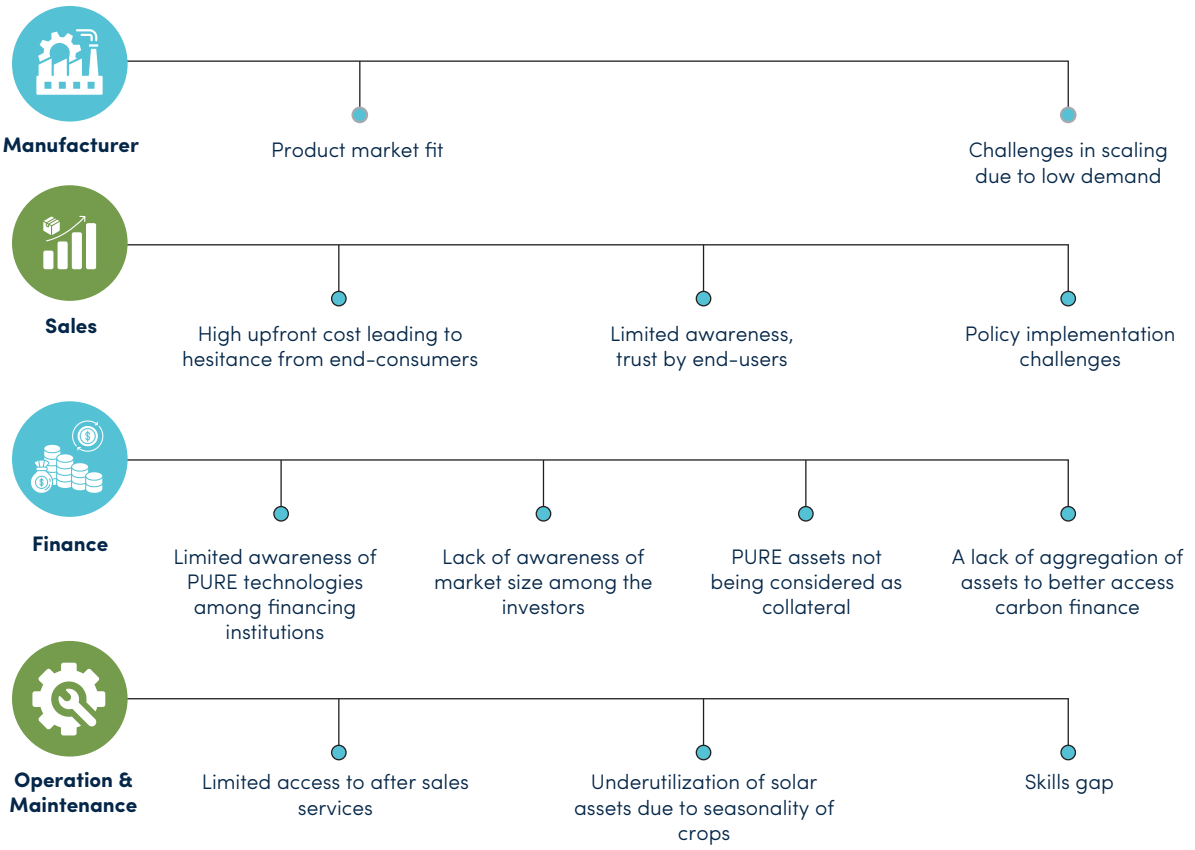
D-RECs can help to bridge this gap by providing a conduit for corporate sustainable finance from multinational corporations for the distributed renewable energy sector in emerging markets.

Indian stakeholders have taken proactive steps to leverage this instrument. Notably, Oorja Development Solutions, in collaboration with climate advisory and finance firm South Pole, is spearheading efforts to generate D-RECs through the deployment of PURE appliances. Through this partnership, South Pole supports Oorja in certifying and commercializing the renewable energy generated by its solar assets using the D-REC platform. This initiative unlocks a new revenue stream, facilitating financing and accelerating the deployment of PURE products in the market.

Recommendations for Enabling Environment

8. Recommendations for Enabling Environment

The previous sections of this report have highlighted the key challenges faced by each PURE product segment, mapping these challenges across the value chain to identify barriers. This section outlines the key recommendations to address these existing hurdles and to enhance the adoption of PURE in India.



Improve Policy Framework

Set up a PURE Taskforce with representation of end-users. The development of PURE products necessitates the involvement of multiple stakeholders from diverse backgrounds, including stakeholders working in renewable energy, agriculture, animal husbandry, fisheries, and more. The MNRE has already initiated the formation of an inter-ministerial steering committee to coordinate support for scaling up PURE initiatives. Additionally, it is essential to ensure the representation of end-users in policy dialogues, which can be facilitated through stewardship councils. These councils play a crucial role in fostering collaboration and ensuring the needs and perspectives of end-users are effectively addressed in the policymaking process.

Mapping of demand through bottom-up approach. Assessing the possibilities and potential of deploying PURE across various sectors of the economy and different regions (including urban regions) is crucial for providing the necessary support for their growth. Adopting a bottom-up approach is essential for accurately assessing the potential of PURE across different sectors. This approach involves analyzing specific needs and conditions at the grassroots level to determine the most effective strategies for deploying PURE technologies in diverse sectors and regions.

Introducing quality standards for PURE. To ensure the scaling up of only high-quality products, ministries should establish standards and testing protocols. These guidelines will specify the required quality criteria for various system components. By setting clear standards,

ministries can ensure that only products meeting these criteria are considered for scaling up. This approach guarantees that the deployed systems are reliable, efficient, and meet the necessary performance standards**.** These quality standards can be aligned with internationally accepted International Electrotechnical Commission (IEC) standards.

Globally certain standards already exist for the quality assurance for off-grid appliances which can be adopted in Indian context.

- VeraSol supports the growing global market for modern off-grid solar solutions with a comprehensive suite of quality assurance services and database of products which act as a source for trusted product performance data.
- GOGLA Consumer Protection Code for off-grid appliances establishes framework for setting minimum standards that every consumer should expect. The code establishes the de facto industry standard for consumer protection that adds value to off-grid solar companies, investors, and other stakeholders.

Adoption of such quality assurance standards for PURE in India will help build the customer confidence and improve the utilization of deployed assets.

Case Study:

VeraSol

VeraSol assists governments and large institutions in developing, adopting, and implementing standards and policies for off-grid solar solutions, maintaining the most widely recognized quality assurance framework for standalone solar systems, endorsed by the International Electrotechnical Commission (IEC). Utilized by governments globally, this framework serves as the foundation for tax and duty policies, voluntary market stimulation programs, and consumer protection regulations, with approximately 35 countries adopting VeraSol quality standards for either mandatory or voluntary enforcement. Verasol currently has product certifications for walk-in cold rooms, refrigerators, solar water pumps, egg incubators, electric pressure cooker, TVs, and fans.

Case Study:

GOGLA Consumer Protection Code

The Consumer Protection (CP) Code establishes a comprehensive framework for the off-grid solar sector, setting the minimum standards every consumer should expect from their provider, applicable to all off-grid solar business models.

It includes an assessment framework enabling companies and investors to measure, demonstrate, and enhance their performance in consumer protection, with 37 indicators tailored to various stages of business growth. Companies committed to the CP Code must conduct an annual self-assessment to maintain public recognition, ensuring regular monitoring and improvement.

Implementation of the CP Code offers PURE consumers several benefits, including informed decision-making, protection from substandard or hazardous products, and enhanced satisfaction with the product's benefits.

Additionally, training technicians for the maintenance of PURE products is essential to ensure their sustained functionality.

Introduction of PURE umbrella policy. An umbrella policy that encompasses support for all PURE products under a single program is essential. This approach consolidates demand for PURE products, making it economically viable for OEMs to manufacture them at scale. Moreover, it facilitates the integration of different PURE products wherever feasible, enhancing the utilization of solar energy generation assets. By streamlining support mechanisms through a unified program, this policy ensures efficient resource allocation and encourages widespread adoption of PURE technologies.

Increase capacity building and research and development

Set up a knowledge hub and provide technical support programs. Technical assistance in capacity building for stakeholders, particularly end-users, on the adoption of PURE products is crucial for driving their increased growth. Additionally, training technicians for the maintenance of PURE products is essential to ensure their sustained functionality. These efforts not only facilitate the widespread adoption of PURE technologies but also create employment opportunities in the process.

Funding for research and development is also necessary to develop PURE products that are well-suited to market needs. Investing in R&D helps ensure that PURE technologies are efficient, effective, and aligned with market demands, ultimately contributing to their successful uptake and scalability.

Case Study:

Skill Development Centre by Sahyadri Farms FPC

Sahyadri Farms, a Farmer Producer Company (FPC), is primarily engaged in horticulture farming, specializing in the cultivation of grapes, strawberries, tomatoes, and other produce. Recognizing the importance of adopting sustainable practices, the FPC has facilitated the integration of PURE (Pro-poor, Urban, Rural Energy) products such as solar dryers and solar water pumps among its farmers. Additionally, Sahyadri Farms has established a Skill Development Centre at its processing site in Nashik to educate farmers on various aspects of agriculture and post-harvest handling.

The impact of such training initiatives is evident in the enhancement of solar dryer operations among the farmers. As Sahyadri Farms supplies horticultural produce to renowned packaged food companies like Kellogg's and Kissan, it is imperative for farmers to adhere to industry standards. Through continuous practice and training within the FPC in association with SustainPlus Energy Foundation, farmers have mastered the art of drying produce, initially starting with grapes, and gradually expanding to include a variety of horticultural crops.

One of the major challenges addressed through continuous learning is the impact of seasonal variations on the processed produce. Farmers have successfully optimized fan speed and drying time using electronic controllers, ensuring consistent drying parameters regardless of ambient humidity and temperature. Moreover, by diversifying crop drying schedules throughout the year, farmers have maximized the utilization of dryers, enabling year-round production.

In addition to technical skills development, Sahyadri Farms has empowered farmers by providing training on marketing strategies, thereby increasing their income generation opportunities. Furthermore, the FPC extends its capacity-building initiatives to neighboring Self-Help Groups (SHGs), assisting them in enhancing their produce quality and fetching higher returns by procuring and selling their products to industry clients.

This continuous learning and capacity-building approach demonstrates its potential for improving the adoption of PURE technologies in India.

Scaling up capacity building for policymakers. Strengthening the awareness and strategic design capabilities of ministries such as Agriculture and Farmer Welfare, Animal Husbandry, and Dairying is vital for promoting the scale-up of PURE technologies in the market. By enhancing their understanding of PURE products and their ability to strategically design policies and initiatives, these ministries can significantly amplify their impact on the promotion and adoption of PURE technologies.

Scaling capacity building of financial institutions. Enhancing the capacity building of financial institutions regarding PURE products is essential for boosting their confidence and facilitating the provision of necessary loans to end-users. By educating financial institutions about the benefits, potential, and viability of PURE technologies, they can better understand the associated risks and opportunities. This increased knowledge and understanding can lead to more informed lending decisions, ultimately supporting the widespread adoption and deployment of PURE solutions across various sectors.

Engaging in demand stimulation initiatives

Awareness among end-users through pilot demonstrations. Raising awareness through demonstration and pilot projects holds significant potential for enhancing technology adoption among end-users and private investors. While there is growing awareness of solar irrigation pumps, particularly through policy coverage and farmer-to-farmer knowledge sharing, other PURE products remain relatively unknown. Without a clear perceived advantage over conventional appliances, the adoption of PURE will be limited. Targeted efforts to demonstrate the benefits and advantages of these technologies, as well as pilot projects showcasing their effectiveness, are essential to increase awareness and promote their adoption.

Case Study:

Solar refrigerators in fish value chain by DD Solar

DD Solar, in collaboration with Villgro Foundation, has initiated a pilot project introducing solar refrigerator units within the fish value chain in Maharashtra's coastal region, specifically targeting the Sindhudurg district. This district is home to numerous fishing-dependent families. The pilot project was implemented in the villages of Tambaldeg and Malwan, offering a 70% subsidy to the fisherman communities. Approximately 100 refrigerators of capacities 100 and 200 liters were provided as part of the pilot.

These refrigerator units serve as crucial storage solutions for fisherman, allowing them to preserve unsold fish catches that would otherwise suffer partial losses due to inadequate refrigeration conditions. Previously, fish were stored using ice, incurring costs for ice procurement and transportation. However, with the introduction of refrigerators, users have reported significant reductions in ice-related expenses and transportation costs, while also observing improvements in fish quality, leading to higher selling prices. Consequently, fisherman have experienced a notable increase in income, estimated at around 10%.

Moreover, beyond the economic benefits, the use of refrigerators has positively impacted the livelihoods of women within the community. Traditionally tasked with selling the fish caught by men, women were also responsible for purchasing ice, often requiring them to travel long distances. The adoption of refrigerator units has eliminated the need for ice procurement, easing the burden on women and improving their overall quality of life.

Encouraged by the positive outcomes observed among users, there has been a growing demand for refrigerators among non-users as well. This increased interest underscores the tangible benefits and effectiveness of solar refrigerator units in fish-related enterprises in coastal communities.

Awareness among the stakeholders. Increasing awareness among stakeholders is crucial for the success of any program. Utilizing education and outreach programs, media campaigns, and fostering community participation not only in rural but also in urban areas could prove to be effective strategies for promoting awareness-raising projects. By engaging stakeholders through these channels, projects can effectively communicate their objectives, benefits, and outcomes, ultimately fostering greater support and participation from the community.

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Conclusion

9. Conclusion

With its large agriculture-dependent population, there is significant potential for the adoption of PURE products in India. The combined addressable market for PURE appliances, including solar water pumps, solar dryers, solar horticulture processors, solar grain mills, solar cold storage, solar refrigerators, solar bulk milk chillers, and solar hydroponic fodder units in the agricultural value chain, is estimated at around US$46 billion[41].

While all these products are solar-based and climate-friendly technologies, they also offer direct benefits to users, such as reducing operational costs and generating additional income, a notable 20-40% income boost for most adopters of PURE products[42]. Moreover, integrating PURE into farm practices holds promise for advancing gender inclusivity, empowering women in farming communities to prosper economically. Numerous success stories exist, such as women-led self-help groups leveraging solar dryers for economic empowerment, or female fish vendors transforming their livelihoods through solar refrigeration.

The PURE ecosystem also has the scope to generate new employment opportunities, especially in the operation and maintenance of PURE products. As a result, PURE appliances are expected to have a positive impact on farming communities, both through their direct and indirect benefits.

Estimates suggest that approximately 35 million farmers and individuals stand to gain from the adoption of PURE products examined in this study. Geographically, the impact potential is concentrated, with the top five states—Uttar Pradesh, West Bengal, Gujarat, Madhya Pradesh, and Maharashtra—contributing roughly half of the country's overall potential.

Certain challenges exist for the growth of PURE along the value chain. Some of them include the right product market fit, high upfront cost, limited awareness, limited access to finance and limited access to after sales support. Currently, some of these challenges are being addressed by the support from government or donor agency support in the form of subsidies and grants. However, to ensure sustained growth in PURE adoption, stakeholders must address longstanding challenges through innovative business and financing models. These innovations might include facilitating pay-per-use arrangements, leveraging local agricultural retailers for PURE distribution, implementing anchor-based financing for risk mitigation, establishing default guarantee funds, and exploring carbon financing avenues.

Government entities and NGOs will also play pivotal roles in this endeavor, primarily by formulating dedicated policies for PURE, informed by bottom-up demand assessments and stringent quality standards. Additionally, enhancing stakeholder awareness and capacity building will be crucial in driving widespread adoption of PURE technologies.

41 Decentralized Renewable Energy Technologies for Sustainable Livelihoods, CEEW (2023)
42 How Decentralized Renewable Energy-powered Technologies Impact Livelihoods, CEEW (2023)

Annexures

Annexure

Annexure-1

Interviewed stakeholders

S.No.	Name of organization	Stakeholder category	Name of respondent	Designation
1	ACUMEN	Impact investment fund	Paraag Sabhlok	Head of Investments, India
2	AgriVijay	DRE distributor	Vimal Panjwani	CEO
3	Bureau of Indian Standard	National Standards Body of India	Debajit Palit	Member – BIS LVDC Committee, and Professor of Energy, NTPC School of Business
4	CEEW	NGO	Wase Khalid	Programme Associate
5	Climate Policy Initiative - IPFF	Financing institution	Saurabh Chandra Rai	Consultant
6	DD Solar	Solar refrigerator OEM	Tushar Devidayal	Founder
7	Hamara Grid Pvt. Ltd.	Solar micro grid developer	Vijay Bhaskar	Managing Director
8	Hydrogreens Agri solutions	Solar hydroponic fodder unit OEM	Vasanth Madhav Kamath	Founder
9	Inficold	Solar based cooling appliance OEM	Nitin Goel	Founder
10	Kissan Dharmbir	Small horticulture processor OEM	Dharmbir Kamboj	CEO
11	Nimbus Solar Solutions	SWP supplier	Mudit Jhunjhunwala	Managing Director
12	Oorja Development Solutions	PURE service provider	Ankur singh	Sr Manager
13	PLUSS Advanced Technologies	Solar dryer, Solar cold storage OEM	Praveen Das	Business Head
14	S4S Technologies	Solar dryer supplier	Nidhi Pant	Co-Founder
15	Samunnati Financial Intermediation & Services Pvt. Ltd.	Financing institution	Sandeep Kumar Siram	Head, Anchor based farmer lending
16	SELCO Foundation	NGO	Supriya Gowda	Program Manager
17	Shakti Pumps (I) ltd.	SWP OEM	Piyush Patidhar	Assistant General Manager
18	Sustain Plus Energy Foundation	NGO	Siddharth Gahoi	Program Manager
19	SwitchOn Foundation	NGO	Ritu Kharayat	Deputy General Manager
20	Temperate Technologies	Solar cold storage OEM	Vishal Singhal	Founder

Annexure-2

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15. LEAP-RE: Long Term EU-AU Research Innovation Partnership on Renewable Energy, LEAP-RE (2020)
16. Financing Solar-powered Livelihoods in India, CEEW (2019)
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