AGRIVOLTAICS

SOLAR AS A THIRD CROP TO AUGMENT FARMERS' INCOME

SUBHODEEP BASU • ASHOK GULATI • ALOK ADHOLEYA

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Editors

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Foreword

India stands at a pivotal moment in its development journey, striving to build a robust economy and achieve the vision of *Viksit Bharat*. Achieving this vision requires strengthening the backbone of the Indian economy which is our farmers. With a large share of the population dependent on agriculture for livelihoods, ensuring higher and more stable farm incomes is not just an economic imperative but a social necessity. At the same time, India must address pressing challenges such as climate change, water scarcity, and food security for its growing population.

Agrivoltaics the integration of solar power generation with agriculture offers an innovative mechanism of aligning economic growth and environment sustainability. By facilitating farmers to co-produce food and clean energy, agrivoltaics enhances agricultural resilience, conserves water, and diversifies income sources. Countries around the world have already begun leveraging this approach, demonstrating its potential to boost rural prosperity while supporting national renewable energy targets. In India, where landholdings are small and fragmented, agrivoltaics could be a game-changer, provided the right policies and institutional frameworks are in place

This report explores the transformative potential of agrivoltaics globally as well as in India. It examines the economic, environmental and social benefits of the approach while discussing key challenges such as land constraints, high initial costs, and policy gaps. It also highlights strategies to scale agrivoltaics through farmer-centric policies, financial incentives, and technological innovations.

As India moves towards a greener and more resilient agricultural economy, agrivoltaics stands out as a practical and scalable solution. The insights and recommendations in this report will be of value for policymakers, researchers, and stakeholders looking to integrate agrivoltaics into India's agricultural landscape. By fostering an enabling ecosystem, India can empower its farmers to become both food and energy producers, driving the nation towards a more prosperous and sustainable future.

Deepak Mishra

Director and Chief Executive, ICRIER

Executive Summary

India has emerged as a global leader in energy transition, with solar power driving its shift toward clean energy. Over the past decade, the country's renewable energy capacity has surged from ~36 GW to 156 GW (excluding large hydro), with utility-scale solar contributing a significant 45.5% of the present installed RE capacity. Of India's total installed solar capacity of 92.1 GW (as of October 2024), utility-scale solar dominates at 77%, followed by rooftop solar (15.6%), off-grid solar (4.2%), and solar hybrid systems (2.8%). While utility-scale solar projects are advancing at a rapid pace, agriculture—a cornerstone of India's economy—has yet to harness the benefits of this rapid and remarkable progress fully. Solarisation in Indian agriculture has majorly been restricted towards the adoption of off-grid solar pumps that primarily target the di-dieselisation of the minor irrigation economy. This fact becomes evidently clear if one looks at the progress of India's flagship scheme of PM-KUSUM aiming for the solarisation of Indian agriculture. The progress in terms of the percentage of implementation over sanctioned pumps for Component B (Off-grid component) stands at roughly 37.19% as on September 2024, while the figures are abysmally low for its grid-connected components A and C. Only 298.83 MW has been installed under Component A against a sanction of 9110 MW (3.28%) while under Component C, only 2.77% and 0.96% have been installed against the total sanctioned pumps under the two variants of IPS (Individual-Pump Solarisation) and FLS (Feeder-level solarisation) respectively. While there are miles to go in terms of solarising Indian agriculture, one might also need to tread with caution when it comes to the adoption of solar in the Indian context. Expanding solar installations risks competing with agriculture for land, presenting a significant challenge for countries like India, where 60% of the land is already under cultivation (World Bank, 2021).

India has emerged victorious in its arduous battle against food insecurity, however, globally the situation is quite concerning. The global challenges of food security and energy transition are intensifying, with the global population projected to reach 9.7 billion by 2050 (UN World Population Projection, 2022). To meet the increased food demand, agricultural production must rise by 70%, requiring an additional 70-80 million hectares of cropland by 2030 (McKinsey & Company, 2023). Simultaneously, the energy demand is surging due to rising living standards and industrialization, necessitating a transformation in the energy sector towards low-emission sources like solar energy. Thus, it is crucial to adopt a strategy that enables the adoption of clean energy sources without jeopardising food security while also simultaneously alleviating the livelihood outcomes of the farmers. One possible innovation that has been gaining a lot of traction in recent times to tackle this plethora of challenges is the concept of Agrivoltaics. Agrivoltaics (APV) combines solar energy generation with agricultural production, offering a dual-use model that maximizes land efficiency and boosts farmer incomes. By integrating solar systems into farming, APV introduces solar energy as a "third crop," aligning India's energy transition with agricultural growth. This study examines APV's potential to significantly enhance farmer incomes while supporting the country's clean energy goals. With the Prime Minister's 2016 call to double farmers' incomes, agrivoltaics emerges as a transformative solution, not only meeting this goal but potentially surpassing it, paving the way for a more sustainable and prosperous future for our "annadatas."

The report has reviewed the technological innovations surrounding agrivoltaics that have taken place globally and what India could possibly leverage from that experience. It has reviewed the existing policies related to agrivoltaics to secure agriculture interests in different countries and India's possible key takeaways if India decides to have a designated policy in APV in the future. Sources such as International Renewable Energy Agency (IRENA), International Energy Outlook, International Energy Agency (IEA), Fraunhofer ISE and PV Magazine have been used for analyzing the same. Earlier reports published by organizations working in APV in India have been looked at to understand the status of implementation in the country in terms of the geographical concentration of the plants, the type of institutions involved in the APV plants in India, and the cropping pattern that are majorly being grown in those plants. Next, data from MNRE's PM-KUSUM portal have been cited to understand the progress in the three different components of the scheme and what could that possibly imply for APV's scope in the country. To understand the economic feasibility of APV in the country, data from a field visit to Sunmaster's Najafgarh Plant and stakeholder consultation with a private developer were utilized. Capital budgeting measures like NPV, IRR, and Payback period were computed to understand the economic viability and profitability of such an innovation. Insights and data gathered during field visits to KVK Ujwa and CAZRI Jodhpur were captured to develop case studies of field experiments of agrivoltaics in the country. Finally based on the insights that emanated from the field visits, stakeholder consultation, and secondary research on Agrivoltaics, a policy recommendation section has been conceptualized to discuss the policy way forward to accelerate and scale such innovation across the country.

In this report, we have explored agrivoltaics as a strategy to augment farmers' income in India vis-à-vis meeting the energy transition goals of the nation. **Chapter 1** addresses the historical competition faced by agricultural land from alternative uses, including the recent expansion of ground-mounted PV that intensifies land conflicts. This chapter emphasizes the need for efficient APV system designs to realize their benefits, detailing essential components and configurations. APV in India is in its early stages so valuable lessons can be drawn from mature international models to guide policymakers in scaling this innovation effectively. The chapter sheds light on global case studies from China, Germany, the US, and Japan, showcasing APV's versatility in optimizing land use, enhancing agricultural productivity and augmenting farmers' income. Moving on from global experiences to India-specific discussion, **Chapter 2** examines existing APV projects in the country in terms of geographical coverage of those projects, the type of institutions involved in them and the crops that are majorly being grown in those projects. The chapter sheds light on the challenges of APV adoption and suggests measures to address those bottlenecks. The insights from Chapter 2 lead into **Chapter 3,** which talks about the PM-KUSUM scheme—a flagship initiative aimed at solarizing Indian agriculture. The chapter examines how APV can be integrated within the scheme to overcome existing barriers like high capital costs and restrictive land-use regulations. It discusses innovative business models, such as farmer-developer partnerships, that can optimize APV's benefits while navigating the challenges. This chapter underscores the synergy between APV and PM-KUSUM, demonstrating how targeted policy adjustments could enhance the scheme's impact. **Chapter 4** builds on the economic implications discussed in Chapter 3 by evaluating the financial viability of APV systems in different scenarios. These scenarios include the cultivation of shading crops by developers or farmers and their financial implications on the APV and farmers. Also, economic feasibility is analyzed under varying mounting heights. By assessing the income potential for farmers participating in APV as power producers or land leasers, this chapter highlights the economic benefits that can be unlocked through dual land use. It emphasizes the importance of tailored APV designs that align with local crop suitability, reinforcing the business case for farmers and making a strong case for APV's scalability.

The high capital expenditure of Agri-PV poses impediments to accelerating the adoption of the technology among small and marginal farmers. As a possible solution for the future, **Chapter 5** shifts focus to the collective potential of farmer institutions, such as solar cooperatives and FPOs as effective institutions in driving APV adoption by smallholders. The chapter argues that these groups can play a critical role in scaling APV by pooling resources, leveraging collective bargaining power, and reducing the financial burden of individual farmers in setting up APV plants. It calls for policy support to empower these institutions, highlighting the importance of collective action in overcoming the financial and logistical challenges of APV deployment. **Chapter 6** discusses two case studies of APV pilots in the country that have been implemented by research institutions in India. These case studies explore agrivoltaics (APV) as a transformative solution for India's dual challenge of sustainable energy production and agricultural income enhancement. They highlight pioneering APV projects at KVK Ujwa and ICAR-CAZRI, showcasing their potential to boost farmer incomes through integrated solar energy and crop cultivation. Both models emphasize efficient land use, water management, and farmer-centric designs, demonstrating significant economic benefits despite minor yield reductions. The studies underline the need for policy reforms, including expanding APV under PM-KUSUM, promoting smaller capacity plants, and enhancing farmer involvement. They offer replicable blueprints for scaling APV to balance energy transition goals with agricultural sustainability.

Drawing on the discussions of technological, economic, and institutional challenges, **Chapter 7** presents a way forward for APV in the country by discussing a possible policy framework to scale this innovation. This has been developed through stakeholder consultations involving farmers, private players, and subject matter experts. This chapter also synthesizes the insights from previous chapters, offering targeted recommendations to address the barriers to APV adoption. It calls for coordinated policy actions to create an enabling environment that supports APV's growth, ensuring that it contributes meaningfully to India's renewable energy and agricultural development goals.

APV is a critical solution at the intersection of agriculture and renewable energy, addressing key challenges of land use, food security, and most importantly income stability for farmers. By integrating solar energy with traditional farming, APV aligns with India's net-zero ambitions and provides a pathway for enhancing farmers' livelihoods. This report underscores the transformative potential of APV to drive sustainable development in India, offering a dual-income model that supports the nation's renewable energy targets and the economic well-being of its agricultural communities.

Editors

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List of Abbreviations

APV:	Agrivoltaics
APPC:	Average Power Purchase Cost
CAGR:	Compound Annual Growth Rate
CAZRI:	Central Arid Zone Research Institute
Capex:	Capital Expenditure
DISCOMs:	Distributed Companies
DFI:	Doubling Farmer's Income
GHI:	Global Horizontal Irradiance
GW:	Gigawatt
GWp:	Gigawatt peak
HSAT:	Horizontal Single Axis Tracking
FAO:	Food and Agriculture Organisation
FLS:	Feeder Level Solarisation
FIT:	Feed – In- Tariff
FIP:	Feed – In- Premium
FPO:	Farmer Producer Organisation
IGEF:	Indo-German Energy Forum
IPS:	Individual Pump Solarisation
ITC:	Investment Tax Credit
kW:	Kilowatt
LCOE :	Levelized Cost of Electricity
LER:	Land Equivalent Ratio
LSPV:	Large Scale Solar Photovoltaics
MGVCL:	Madhya Gujrat Vij Company Limited
MNRE:	Ministry of New and Renewable Energy
MOAFW:	Ministry of Agriculture and Farmers' Welfare
NSEFI:	National Solar Energy Federation of India
MW:	Megawatt
Opex:	Operation Expenditure
PM-KUSUM:	Pradhan Mantri Kisan Urja Suraksha Evam Uttaan Mahaabhiyan
PV:	Photovoltaics
RPS:	Renewable Portfolio Standard
SERC:	State Electricity Regulatory Commission
SDG:	Sustainable Development Goals
SPICE:	Solar Pump Irrigators Cooperative Enterprise
TW:	Terawatt
VSAT:	Vertical Single Axis Tracking
WEF:	Water, Energy, Food

Abstract

Land use competition between agriculture and industry has been a persistent issue throughout history, and the push for energy transition has intensified this. Co-locating agriculture with solar power generation has emerged as an innovative solution. For India, achieving ambitious net-zero targets requires rapid expansion of solar energy that rely on more than large-scale utility plants or residential rooftop solar initiatives. With agriculture accounting for 45.5% of India's employed labour force, as per the latest Periodic Labour Force Survey (PLFS) 2022-23 report, there is a need to secure stable income for our farmers. Integrating agriculture into India's renewable energy goals is crucial for achieving net-zero targets, ensuring food security and boosting farmers' livelihoods. Policymakers across the globe are looking to agrivoltaics as a promising solution to achieve these. APV combines agricultural activities with solar energy generation and is being recognized as a promising strategy to optimize food and energy security. Solar power is land-intensive, so large land swathes must be made available. As per the World Bank, sixty percent of India's land area is farmed (World Bank, 2021), a much higher share than the world average of 39%, making APV in India better placed than other countries to relieve pressure on land and ecosystems. In Indian agriculture, there has been a long-standing problem of low and unstable incomes exacerbated by climate change. If farmers of varying landholding sizes participate in APV systems as power producers or land leasers while continuing cultivation, solar power could be a remunerative third crop.

In this report, the global landscape of APV and the critical technological, policy, and economic issues surrounding APV in India have been studied. A diverse group of stakeholders - farmers, solar developers, financiers, distribution utilities - participate in the APV systems. The study has examined the economic feasibility of implementing APV by key stakeholders. Eighty percent of the Indian farmers are smallholders with limited capital available for investment in innovation. In that context, the study has reviewed the possibility of engaging farmer enterprises such as FPOs and cooperative societies to take such models forward. The role of government programs such as PM-KUSUM have been addressed in the context of India's journey of solarising agriculture. The report explores how APV can be integrated into the existing scheme to address key barriers like high capital costs and restrictive land-use regulations. It highlights innovative business models, such as farmer-developer partnerships, that maximize APV benefits while tackling the unique challenges of implementing such innovations in India. Finally, a comprehensive policy framework has been developed to highlight key policy interventions required to make such innovations a success in India. APV has the potential to address several predicaments in India's agriculture and energy sector since such models enhance farmers' income while facilitating their diversification into high-value crops. In essence, APV presents a transformative opportunity for India's agriculture and energy sectors, offering a pathway to increase farmers' incomes, promote sustainable practices, and drive the nation closer to its renewable energy goals.

1

Global Developments in Agriphotovoltaics (APV)

Key Learnings for India

Laxmi Sharma and Bidisha Banerjee

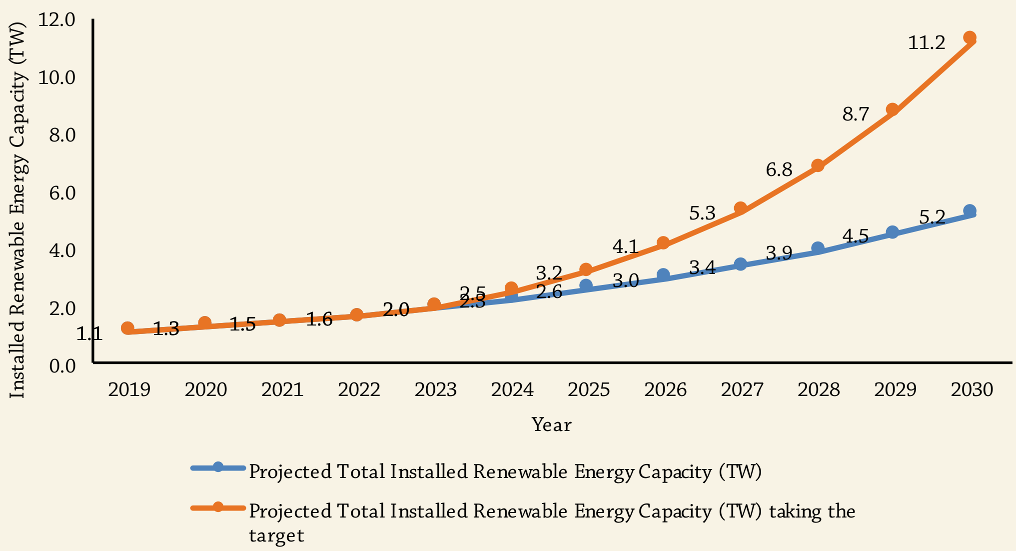
Introduction

The rising world population, living standards, and industrialization increase the global energy demand (Zhang & Wang, 2018). According to recent projections, energy demand is projected to grow to almost 30% by 2030 (International Energy Agency (IEA), 2024). Globally, non-renewable energy sources dominate electricity production, up to 60-80%, to generate electricity (IRENA, 2021). Coal and natural gas are the primary non-renewable energy sources. Non-renewable environmental impacts such as greenhouse emissions, air pollution, and water pollution highlight the importance of transitioning to renewable energy sources to ensure a sustainable future. To combat this, countries around the world, including the UK, Japan, USA, and Canada, are aiming to achieve net-zero emissions by 2050 by deploying low-emissions energy from renewable sources (IEA, 2021).

Figure 1.1 presents the global installed renewable energy capacity over the last five years (2019–2023) as per IRENA and the projec-

FIGURE 1.1

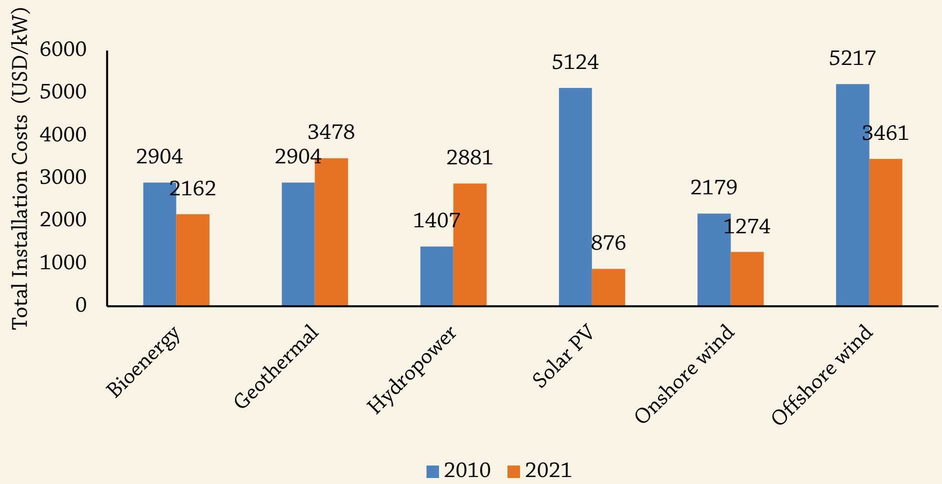
Projected Total Installed Renewable Energy Capacity Globally (TW) till 2030: Expected Trends vs. Target Achievement Scenario



Source: International Renewable Energy Agency (IRENA) and Author's Analysis.

FIGURE 1.2

Total Installation Cost of Various Renewables



Source: IRENA.

tions to 2030, based on the Cumulative Annual Growth Rate (CAGR) method (as per author's analysis). The data analysis interprets a CAGR of 14.87% for global installed renewable capacity, projecting approximately 5.2 TW by 2030 under the ongoing scenario. With the target set at 11.2 TW quoted by IRENA, the data analysis shows that the CAGR needs to rise to 28.28%, meaning there should be an average annual increase of 1 TW to reach the target.[1] This underscores the need for a rapid and large-scale expansion of the renewable energy sector; particularly wind and solar to meet future goals.

Solar energy as a crucial renewable energy resource is exponentially increasing every year in terms of installed capacity. Globally, the cumulative Solar PV capacity is 1412 GW at the end of 2023. In 2022-2023, there was an increase in capacity of 345 GW, the highest year-on-year addition in the past decade (IRENA, 2023). One of the possible reasons for such a rapid growth is the decline in the total installation cost from 5124USD/kW to 876USD/kW over ten years, from 2010 to 2021 (IRENA, 2021), as shown in **Figure 1.2**. There was also a 90% decrease in the Levelized Cost of Electricity (LCOE) from 2010 to 2023, which has made solar PV 56% more affordable than a weighted average of fossil fuel-fired alternatives (World Solar Market Report 2024). With economies of scale driving down costs, it's projected that over 40% of the world's renewable energy by 2050 will come from photovoltaic (PV) installations (IEA, 2022).

In the Solar PV sector, ground-mounted PV accounts for 94.20%, solar rooftops 5.58%, and solar floating panels 0.22% (Kumpanalaisatit et al., 2022). These global trends map onto the Indian context in different ways. India has set a target of reaching net zero emissions by 2070. To fulfil this target, 500 GW of renewable energy must be installed by 2030. Presently, solar energy contributes about 43% of the total renewable energy, with 442 GW of total installed capacity (MNRE, 2024). Among various PV systems, ground mounted Solar PV is land-intensive, requiring 2.5-8 acres of land per MW (NREL, 2013).

India is primarily an agrarian economy, engaging 60% of its total land area and over 45% of its workforce (World Bank, 2021). Historically, agricultural land has faced steep competition from alternative land uses, with non-agricultural land use increasing from 3.86% in 1952-53 to 8.4% in 2021-22 (Land Use Statistics, 2022). Contentious issues surrounding agricultural land include land conversion, adequate compensation for landowning farmers, and the absence of compensation for the

1. Analysis on CAGR calculation done by Author. Refer to Annexure A for further details.

landless (Andreas et al., 2020). Solar power is not immune to this phenomenon. Around 68% of solar installations in India are on agricultural land, and solar projects have encountered conflicts with local communities (Ortiz et al., 2022). There are numerous examples of such conflicts. Farmers in Kamuthi, Tamil Nadu, protested against the construction of the largest solar park in India (in 2016), alleging agricultural land grab for the same (Sridhar et al., 2024). In 2018, farmers challenged the allotment of about 3800 acres of land for a solar project in Jaisalmer, Rajasthan, with the High Court eventually cancelling the allotment (Parrikar, 2021). In 2021, a 15 MW solar project in Nagaon, Assam, became the source of conflict between farmers and developers with allegations of forced land grab and eviction (Deka, 2021). While farmers face livelihood loss due to stiff land-use competition, developers face legal and financial implications (Chari, 2020). Co-locating solar projects on agricultural land may solve this historical problem, balancing energy transition with food security while protecting rural livelihoods. Integrating PV with agriculture makes it possible to meet renewable energy targets without compromising agricultural productivity. This boosts electricity generation from renewable sources and provides farmers with an additional income by selling electricity to the grid, effectively turning solar energy as a third crop (Gulati, 2022).

APV as a Possible Solution?

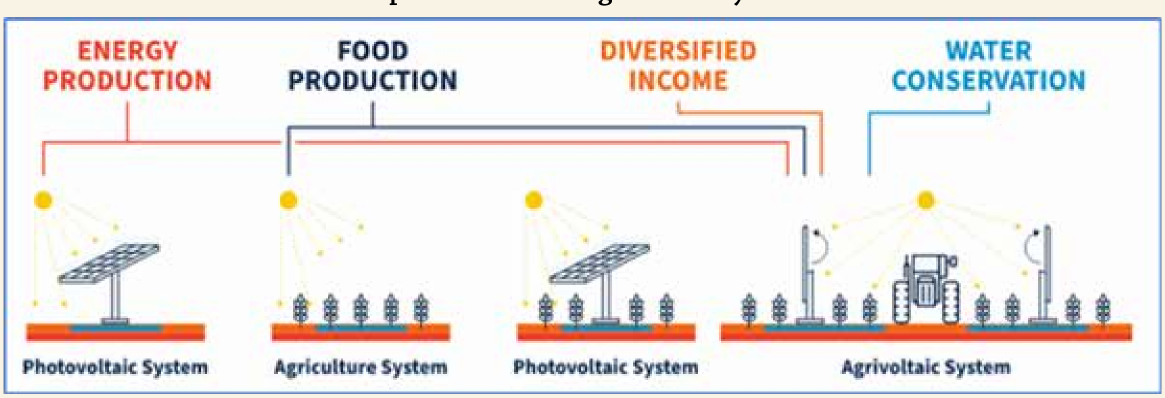
APV is the combination of 'Photovoltaic 'and 'Agriculture' Systems that enables dual land use for agriculture and PV power generation and increases land use efficiency. Developed by German scientists (Adolf Goetzberger and Armin Zastrow) in the 1980s, this optimizes agricultural land use (Trommsdroff et al., 2022). It has been known by various terms such as APV, APV solar sharing, and PV agriculture. Although APV is in its early stages in India, the technology has gained significant momentum globally. Its versatility lies in its ability to impact multiple aspects of the agricultural system—energy generation, food production, livelihood enhancement, and water conservation **(Figure 1.3)**. The next part of the chapter delves into the global evolution of APV, highlighting its potential benefits **(Figure 1.4)**. It also covers key components and system designs of a typical APV plant and the global case studies showcase how APV can empower agricultural communities, offering crucial insights to embark on the country's APV expansion journey successfully.

Benefits of APV

APV System provides various benefits to sustain food, energy, the environment, the society and the economy. **Figure 1.4** presents the various benefits of APV.

FIGURE 1.3

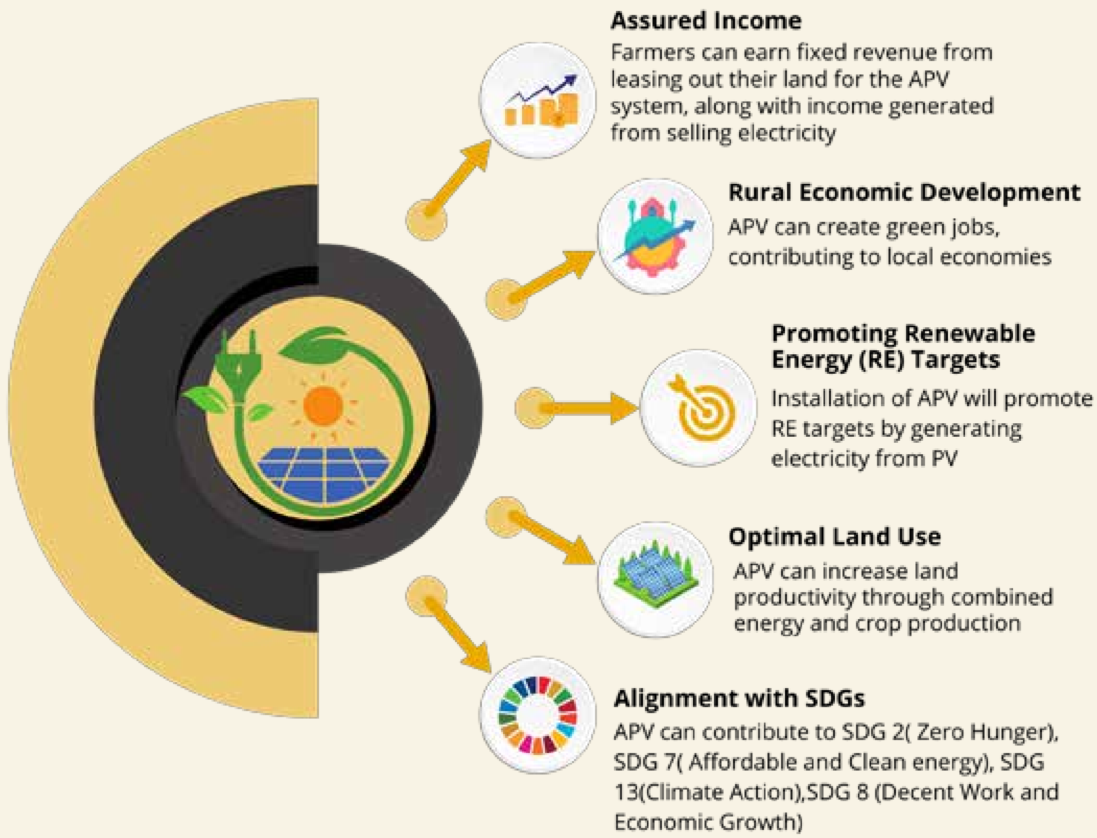
Representation of Agrivoltaic System



Source: University of Illinois.

FIGURE 1.4

Significance of APV



Source: Author's Own.

Evolution of APV

APV has evolved since the 1980s from an experimental concept to a promising innovation for sustainable agricultural land use. As shown in **Figure 1.5** in 1981, German scientists Adolf Goetzberger and Armin Zastrow, in their publication "Photovoltaics-System for Agriculture," introduced and formalized the integration of solar PV systems with agricultural land. This paper laid the foundation for APV work in Germany and other countries. Many leading countries have been doing experimental research pilots to understand the effects of shading due to solar panels on crop yields to understand the overall feasibility of APV systems

The deployment of APV has grown significantly in recent years, from 5 megawatts of peak energy in 2012 to 14 gigawatts in 2021 (GEF, 2024). Countries leading in APV implementation are China, Japan, South Korea, Germany, Italy, France, and the US.

The rapid expansion of APV highlights the importance of efficient system design to maximize its benefits. To realize the potential of these systems, it is crucial to understand the essential components and configurations that make them effective.

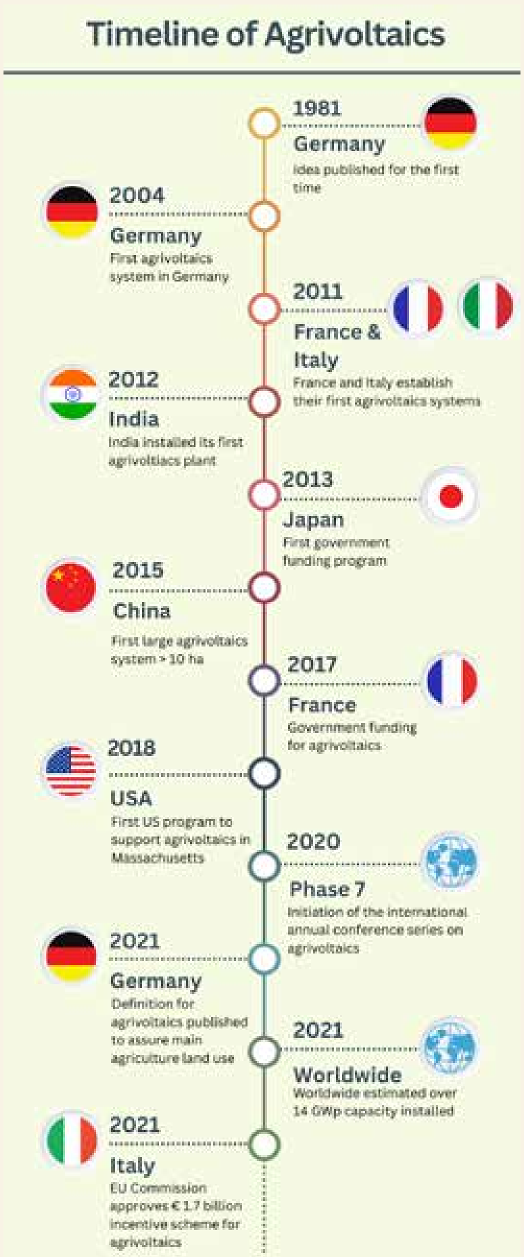
Components of an APV Plant

An APV plant integrates several key components to optimize energy generation and agricultural productivity as shown in **Figure 1.6**.

- Solar Panels: Solar panels, or photovoltaic (PV) panels, convert sunlight into electricity using solar cells, typically made of silicon. An APV system's primary role is to generate renewable energy while coexisting with crop production. Strategically positioned, these panels capture sunlight efficiently without affecting the crop growth beneath them.

FIGURE 1.5

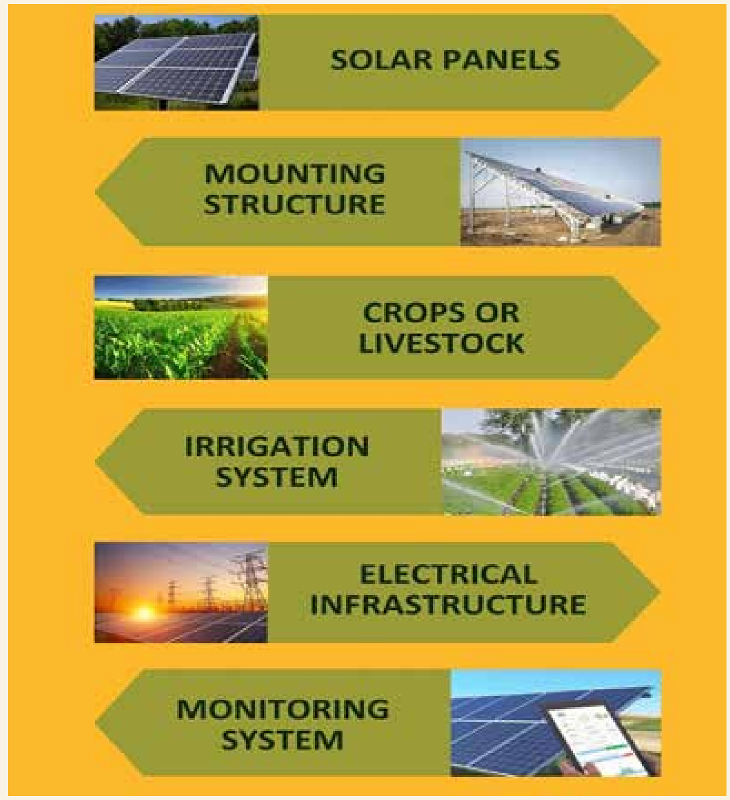
Evolution of APV



Source: Fraunhofer ISE.

FIGURE 1.6

Components of an APV Plant



Source: Fraunhofer ISE.

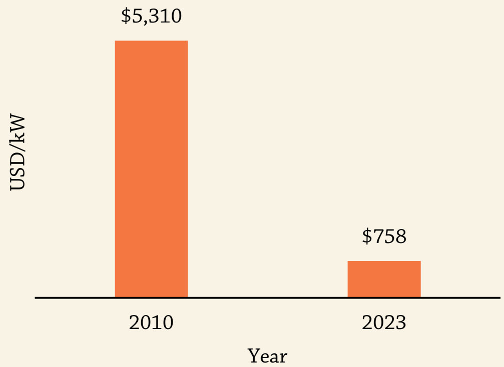
- Mounting Structure: A mounting structure is a framework that supports and holds solar panels in place. In APV systems, it elevates panels at optimal angles for sunlight capture while ensuring stability against wind and weather. These structures allow for adjustments and provide space for farming activities underneath, facilitating the coexistence of agriculture and solar energy generation.
- Crop or Livestock: Crops are plants grown for food or other products, while livestock refers to domesticated animals raised for food, labour, or other uses. Both are vital for food production and agricultural sustainability.
- Irrigation System: Irrigation systems supply water to crops using drip or sprinkler irrigation methods, ensuring efficient water use and soil moisture. In APV systems, they maintain optimal moisture levels for crops beneath solar panels, supporting productivity and maximizing yields.
- Electrical Infrastructure: Electrical infrastructure in APV plants includes components like inverters, transformers, and wiring that manage the conversion and evacuation of solar energy. It ensures efficient energy flow to the grid or local usage while supporting the overall functionality of the APV system.

- Monitoring System: A monitoring system in APV plants tracks solar energy production, crop health, and environmental conditions using sensors and software. It enables real-time adjustments to optimize performance and enhance the sustainability of energy generation and agricultural output.

The utility-scale solar sector has seen remarkable cost reductions over the past decade. In 2023, the global weighted average installed cost hit a record low of USD 758/kW in 2023 from USD 5310/kW in 2010 as shown in **Figure 1.7**.

FIGURE 1.7

Global Weighted Average Total Installed Costs (in USD/kW) for Utility Scale Solar- By Component 2010-2023



Source: International Solar Alliance, 2024.

Usage of Various Solar Panels in APV

The previous section provided an overview of the APV system components, highlighting the importance of

FIGURE 1.8

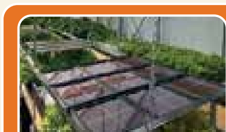
Classification of Solar Panels

Monocrystalline Solar Panels
- Offer 15% to 22% efficiency. (Chandra, 2023)
- Ideal for areas with limited space due to high energy density.
- Perform well in low-light conditions, ensuring year-round energy production.
- Durable and reliable for long-term use.
- Higher cost due to complex pure silicon crystal manufacturing.

Polycrystalline Solar Panels
- Offer 15% to 17% efficiency. (Nexamp, 2023)
- More cost-effective, ideal for larger installations.
- Less efficient than monocrystalline but suitable for large-scale agricultural projects.
- Easier and faster to produce, reducing installation time.

Bifacial Solar Panels
- Capture sunlight on both sides, boosting energy output.
- Highly effective in reflective environments.
- Increase energy yields by up to 30% compared to monofacial panels. (Renogy, 2024)
- Durable and resistant to snow and wind.
- Higher initial cost but provides long-term benefits through enhanced performance.

Thin-film Solar Panels
- Offer 7% to 12% efficiency but are lightweight and flexible. (Bailey, 2023)
- Suitable for installation on greenhouses and curved structures.
- Perform well in high temperatures and areas with indirect sunlight.
- Easier to manufacture and install, reducing costs despite lower efficiency.



Transparent Solar Panels
- Allow sunlight to pass through while generating electricity.
- Beneficial for crops that thrive in filtered sunlight.
- Early in commercialization.

Source: Author's Own.

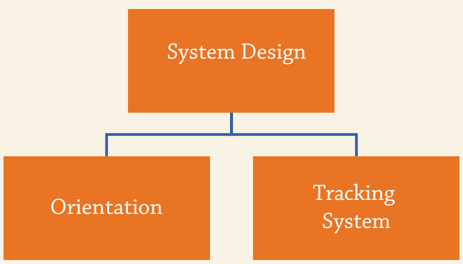
solar panels. In terms of solar panels, there are different modules, such as monocrystalline, polycrystalline, and thin film that have distinct characteristics that influence efficiency, space requirements, and shading impacts as shown in **Figure 1.8**.

System Design of an APV Plant

Optimal System design improves the efficiency of an APV system. It integrates solar technology and agricultural production, optimizing solar panels, configurations, and tracking systems for energy production and crop health. A well-thought-out design maximizes energy generation and agricultural productivity benefits, optimizing land use and resource efficiency.

FIGURE 1.9

Aspects of System Design in APV



Source: Author's Own.

System design in an APV setup considers two aspects as shown in **Figure 1.9**.

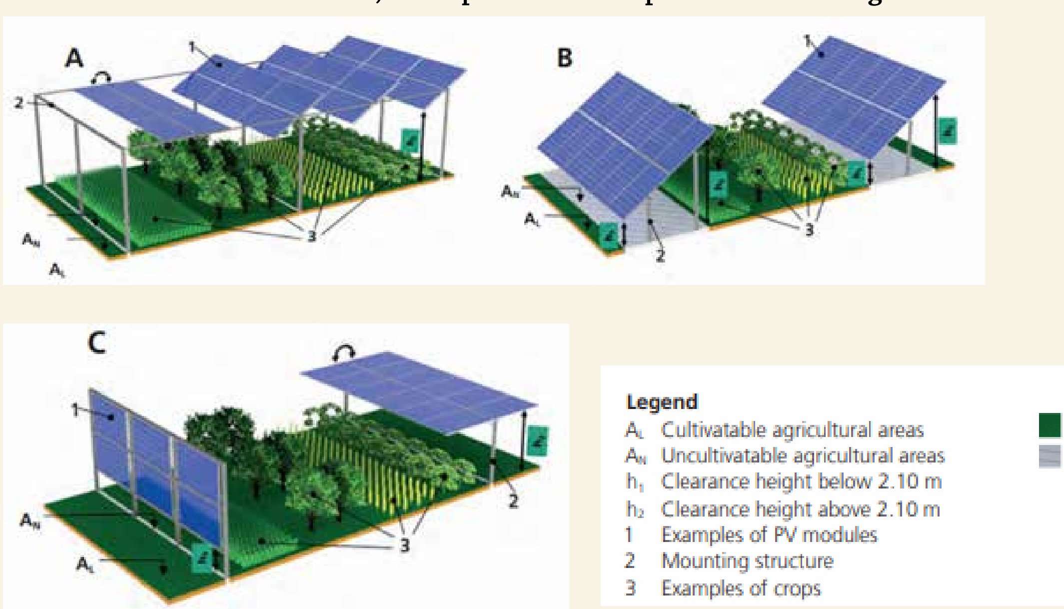
- Orientation of APV plant: In an APV plant, orientation refers to positioning of solar panels relative to the sun and the crops below. It involves the angle and alignment of the panels to optimize sunlight exposure while minimizing shading.
- Tracking system used in APV plant: A tracking system adjusts the position of solar panels throughout the day to follow the sun's movement. This maximizes sunlight capture and energy generation by maintaining optimal panel angles.

Orientation in APV

Orientation in an APV plant helps to optimize energy generation and agricultural productivity. Properly positioned solar panels maximize sunlight capture, leading to higher energy output. The right orientation can provide partial shade, reducing heat stress and evaporation for specific crops. There are three main types of orientations that are considered when designing an APV plant. **Figure 1.10** and **Figure 1.11** show the illustrations and the description of these orientations.

FIGURE 1.10

Illustration of Overhead Stilted, Interspace and Interspace Vertical Configuration for APV



Source: Fraunhofer Institute of Solar Energy Systems (ISE).

FIGURE 1.11

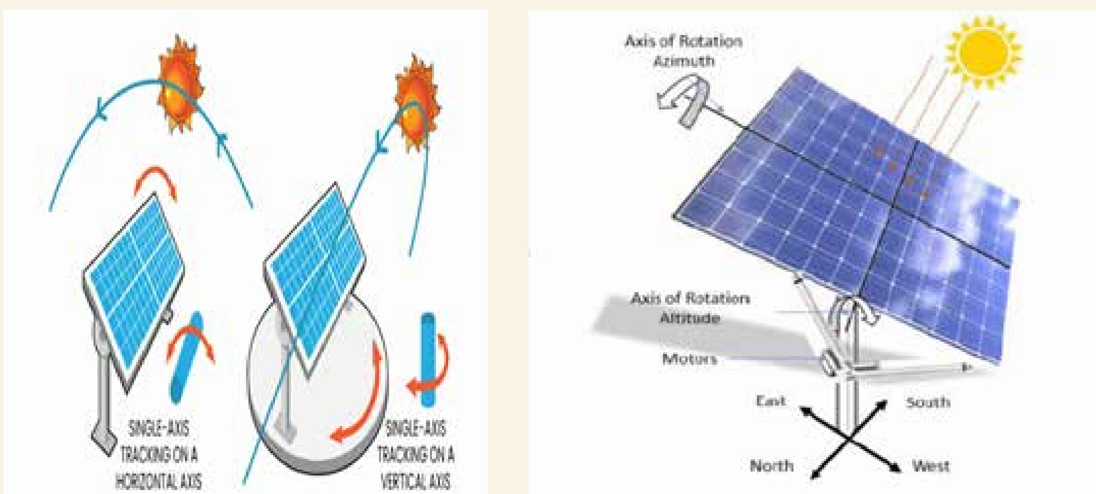
Details about Variety of Orientation in APV

Overhead Stilted Configuration	Interspace Configuration	Interspace Vertical Configuration
• Solar modules are elevated ~3 to 5 meters to allow unobstructed farm machinery use. (Fraunhofer Institute of Solar Energy Systems) • North-South facing panels maximize sunlight and minimize crop shading in northern regions. • East-West facing panels capture morning and afternoon light, reducing heat stress and water loss, ideal for orchards/vine-yards.	• Panels are spaced in a way to allow large machinery to pass easily between rows. • Panels are under 3 to 4 meters height, balancing energy generation and farming needs. (Fraunhofer Institute of Solar Energy Systems) • South-facing orientation maximizes sunlight for energy production and crop growth.	• Panels are mounted vertically on poles, allowing uninterrupted farming while generating electricity. • Panels act as windbreaks, reducing wind speed, protecting crops from excessive sunlight, and minimizing soil erosion. • Vertical panels capture sunlight throughout the day but yield less energy than horizontal setups.

Source: Fraunhofer Institute of Solar Energy Systems (ISE).

FIGURE 1.12

Illustration of Single-Axis and Dual-Axis Tracking System



Source: Sinovoltaics and Research Gate (Performance Evaluation of Fixed and Sun Tracking Photovoltaic Systems).

Each APV configuration offers benefits depending on the type of crops grown, climate, and the agricultural practices employed. For example, the overhead stilted configuration is ideal for row crops that benefit from partial shading, while the interspace vertical configuration is helpful for crops that need wind protection or are grown in regions with high soil erosion risks. APV systems are designed to be adaptable, allowing farmers to choose a configuration that fulfils the requirements.

FIGURE 1.13

Details about Types of Tracking System in APV

Single-Axis Tracking System	Double-Axis Tracking System
• Enables panels to rotate on an axis, boosting energy production with a simple design. • Horizontal Single-Axis Tracking Panels tilt horizontally from east to west, maximizing energy capture and ensuring sunlight for crops below. • Vertical-Single Axis Tracking Panels rotate vertically, managing shading for heat-sensitive crops while maintaining a fixed tilt (Lane and Cappuccio, 2024).	• Rotate on both horizontal and vertical axes, following the sun throughout the day and across seasons for maximum efficiency. • Panels adjust to higher angles in summer for direct sunlight and lower angles in winter for optimal energy capture (Bolt, 2024).

Source: Author's Own.

Tracking Systems in APV

A tracking system in an APV adjusts solar panels throughout the day to follow the sun's movement, optimizing sunlight capture and significantly increasing energy production compared to a fixed tilt system. Tracking systems adapt to seasonal variations in sunlight, supporting sustainability and efficiency in integrated land use. Two types of tracking systems are considered for designing an APV setup. **Figure 1.12** and **Figure 1.13** show the illustrations and description of the two types of tracking systems.

The selection of tracking systems in an APV depends on the crops, local climate, and energy goals. Single-axis systems are cost-effective and easy to maintain. Dual-axis systems, though more complex and expensive, offer enhanced efficiency and are suited for areas with seasonal sunlight variations, benefiting high-value crops where optimizing energy and output is crucial (Solar Square, 2022).

Other Factors for Setting up an APV Plant

The orientation and tracking play a major role in the system design of an APV setup but planning an APV plant includes parameters beyond the technical aspects of solar panel configurations and tracking systems. Some of the factors are shown in **Figure 1.14** below.

FIGURE 1.14

Factors for Setting up an APV Plant

Technical and Infrastructure Considerations	• Drainage system • Access for maintenance
Environmental Considerations	• Environmental impact assessments • Soil health (Next2Sun, 2024)
Community and Stakeholder Engagement	• Public consultations • Capacity building and trainings
Site-Specific Factors	• Water supply sources • Crop types • Humidity and monsoon phase
Economic Considerations	• Landholding size • Land lease rates • Project financing (Krishnan et al., 2024)

Source: Author's Own.

- Technical and Infrastructure Considerations
  - o A well-planned drainage system manages water flow and prevents crop waterlogging, ensuring optimal soil health.
  - o Easy access for regular maintenance minimizes disruptions to farming while keeping the APV system performing optimally.

- Environmental Considerations
    - o Conducting thorough assessments helps identify risks to ecosystems, soil health, and biodiversity, allowing planners to implement necessary mitigation strategies.
    - o Implementing soil conservation practices is vital to preserve soil quality and enhance agricultural productivity.
- Community and Stakeholder Engagement
    - o Engaging local communities early in the process builds trust and support, through public consultations and workshops.
    - o Offering training programs ensures that local farmers and stakeholders effectively utilize and maintain the APV systems.
- Site-Specific Factors
    - o Assessing local water supply sources is useful for sustainable farming practices in APV systems.
    - o Strategic crop selection tailored to site-specific conditions maximizes productivity and complements solar energy generation.
    - o Understanding local climate conditions, including humidity and monsoon phases is vital for optimizing crop yields and energy production.
- Economic Considerations
    - o Analyzing the size of landholdings helps determine the scale and feasibility of implementing APV systems.
    - o Understanding local land lease rates is vital for assessing project costs and profitability.
    - o Evaluating financing options, including power offtake agreements and cost savings with DISCOMs is essential for ensuring financial sustainability.

Application Cases of APV across Globe

APV is being implemented in innovative ways around the world. Few of the cases are given below to highlight the versatility and potential of APV to optimize land use, enhance agricultural productivity, environmental benefits and contribute to RE goals. These cases include crop cultivation, livestock grazing, aquafarming and tea plantations.

Case 1: 51 MW, Yunnan, China owned by Trina Solar

Source: Trina Solar.

Crop Cultivated: Tea Farming

Module Type: Transparent Dual Glass Solar Modules, mounted above the tea plantations.

Design Advantage: Glass solar panels to allow sunlight to reach the tea plantation and ensure that their growth is not jeopardized due to shading hindrance.

Economic Benefit: 80000 kW hours electricity generation annually (Trina Solar, NA).

Environmental Benefit: Reduce CO_2 emissions of 80000 tons annually (Trina Solar, NA).

Case 2: Shizuoka Prefecture, Japan, owned by farmer

Source: Business Insider.

Crops Cultivated: Matcha Green tea, a shade loving crop (needs 90% shading for 3-4 weeks) (Graham, 2022)

Module Type: Overhead with spacing in each panel

Economic Benefit: Five ton of production and 8000 kW electricity generation annually (Graham, 2022)

Environmental Benefit: Provision of Shading.

Case 3: 194.4 KW, Heggelbach, Germany, owned by Fraunhofer ISE

Source: Fraunhofer ISE.

Crop Cultivated: Potato

Module Type: 720 bifacial glass-glass PV module, with south-west alignment at clearance height of 5m and 9.5 m row distance

Economic Benefit: Yield was above 80% as per DIN SPEC Standard (Asa, Reher et.al, 2024)

Environmental Benefit: Land Equivalent Ratio (LER) increased from 1.6 -1.8 (Asa, Reher et.al, 2024).

Case 4: Shandong Province at Yellow River, China, owned by Baofeng Group

Source: WRI.

Crop Cultivated: Shrimp Farming

Module Type: Overhead mounting structure with seven meters above water

Economic Benefit: 260 GW per hour energy produced provided to grid that serves 113000 households (Silan et al., 2021)

Ecological Benefit: Solar panels keep the water temperature consistently 2 to 3 degree C cooler than the outdoor ponds without panels, boosting shrimp and sea cucumber yield by 50%. (Silan et al., 2021).

FIGURE 1.15

Status of APV in Leading Countries

Country	*Installed APV*	*Number of APV*	*Crops*	*Incentives*	*Standardisation/Definition of APV*	*Legal and Policy Framework promoting APV*
China	64 GW (2021)	500 APV plants	Goji Berry Lettuce Spinach Beet Carrot Pumpkin Onion	Tax incentives aimed at agribusiness to reduce cost Subsidised loans Special funds and grants 25 years Power Purchasing Agreements (PPA) for long term revenue certainty by government	No formalised standardisation Detailed streamlined approval process (from initial proposal to grid connection, operation, reporting)	PV poverty alleviation policies to promote APV in rural areas by relaxing strict land policies National level PV power generation front runner base scheme (mainly for developer and manufacturers for deploying efficient and reliable technology) Land use regulation by Ministry of Agriculture and Rural Affairs, to ensure agriculture land used for farming activity
USA	2.8 GW (2023)	314 APV projects	Grazing Pollinator Lettuce Spinach Beet Carrot Radish Tomato	Federal Funding through Foundational APV Research for Megawatt Scale (FARMS) initiative – $8 million Federal Investment Tax offer 30% tax credit for APV installation Renewable Portfolio Standard (RPS) prompted utilities and developers to incentivize APV projects at the state level 20-25 years PPA	No formalised Standardisation Local standards and guidelines by the State	State program: Solar Massachusetts Renewable Target (SMART) Program to provide additional feed in tariff for APV Innovative Solar Practices Integrated with Rural Economies and Ecosystems (InSPIRE) initiative by National Renewable Energy Laboratory (NREL) to understand the best practices and provide foundational data to stakeholders Protecting Future Farmland Act to provide tax relief for land used for agricultural purpose
Germany	14 GW (2021)	NA	White Winter Potato Clover Celery Tomatoes Cucumber Soft fruits	Guaranteed grid access and feed in tariffs Provision of 85% of the standard subsidies (from EU direct payments) granted based on the farm size	DIN SPEC 91434 Agriculture yield must be at least 66% of the reference yield	Common Agricultural Policy by EU to provide 85% subsidy based on the size of the farm. Renewable Energy Sources Act (EEG) to ensure financial, legal and grid access. Construction Regulation to avoid construction APV on unplanned open areas.

Country	*Installed APV*	*Number of APV*	*Crops*	*Incentives*	*Standardisation/Definition of APV*	*Legal and Policy Framework promoting APV*
Japan	200 MW (2021)	1992 APV Plant	Ginger Green Onions Berries Paddy rice	Feed in Tariff scheme in the free market via PPAs Rebate Scheme (giving 50% on upfront cost) Feed in Premium to balance the supply and demand more effectively, reducing the risk of oversupply and managing the grid stability. 5-20 years PPA	No land conversion (land should remain farm land) Yield reduction must be under 20% compared to average level of the surrounding farmland Annual reporting to ensure compliance Mounting structure should be temporary and removeable, maintaining height of between 2 meters – 9 meters	Land Use Policy highlighting APV should be treated as agriculture land Issue of Directives to institutionalise on APV by Ministry of Agriculture, Forestry and Fisheries that allowed installation of APV on all categories of farmland.
India	NA	23 APV plant	Tomato Lettuce Cabbage Legume Carrot	PM KUSUM Component A with no subsidy Feed in tariff scheme 20-25 years PPA	No formalised standardisation	Uttarakhand State Solar policy supporting APV Ambiguity about any legal framework on co-existence of agricultural and non-agricultural activities on the same land.

Sources: Based on various PV magazines.

Case 5: 1.2 MW, Colorado USA owned by farmer

Crop Cultivated: Berries, Carrot, Tomato, Sheep grazing and pollination

Module Type: Single Axis tracker mounted solar Panels

Economic Benefit: Potential of increase in crop production up to 70% (Solar Power World, 2021)

Ecological Benefit: Water usage reduced by 30% as panel lowers the evaporation rate and retains the soil moisture (Solar Power World, 2021).

Source: Solar Power World.

APV continues to grow globally with many countries integrating solar power with agriculture. Leading nations such as China, Germany, the USA, Japan and India are at the forefront of adopting APV, each with its unique approach and successes. **Figure 1.15** provides an overview of the current status of APV in these countries.

Conclusion

India can draw valuable lessons from global APV cases to enhance its own APV efforts. **Figure 1.15** above outlines the critical strategies adopted by leading countries, i.e., including standardization, policy framework, financial support, technological innovations that have helped balance agricultural practices while boosting renewable energy production. For example, Germany has implemented clear standards like DIN SPEC 91434 that ensures agricultural yield remains at least 66% of the reference yield (Fraunhofer ISE, 2022). Japan also enforces necessary conditions to limit yield reductions to no more than 20% compared to the average level of the surrounding farmland. Additionally, Japan's agroclimatic conditions led to the implementation of height regulations for APV structures ranging between 2 and 9 meters (Bellini, 2021).

In India, APV is in its early stages and needs a formal definition or standard for what should ideally constitute an APV system. The experiences of countries like Germany and Japan can provide a roadmap for India to establish its standards. India can establish explicit requirements for planning, operations, documentation, monitoring, agricultural use, and quality assurance to ensure energy and agriculture production while enhancing farmers' income. Moreover, India needs policies that promote APV at both the central and state levels. Taking lessons from research and commercial pilots from countries like China, Japan, Germany, and the US, India can leverage the policy and legal framework of APV to make it more robust. India's diverse agroclimatic conditions necessitate a tailored approach when implementing APV systems. The next chapter discusses the need and modus operandi of this tailored approach, along with an overview of the status of APV projects in India.

2

Overview of APV Plants in India

Bidisha Banerjee

Introduction

Agriculture employs 45% of India's labour force and contributes 18.2% to the GDP, with over 60% of land available for cultivation compared to the global average of 38% (MoSPI, 2023; Ministry of Finance and Corporate Affairs, 2024; CIA, 2018; World Bank, 2021). However, 80% of Indian farmers are smallholders with less than 2 hectares of land (WEF, 2021). Given the sector's importance, innovations that enhance productivity and profitability, like APV, are essential. APV allows farmers to earn from renewable energy while diversifying into high-value crops, particularly shade-tolerant horticulture that shows an increased productivity in APV setups compared to staple grains like rice and wheat (Ghosh, 2023).

However, the success of APV depends on selecting suitable regions and crops, given India's geographical and ecological diversity. Identifying regions where APV is economically and environmentally viable is crucial for targeted implementation. This chapter covers key areas including the criteria for selecting regions and an overview of existing APV plants and the crops they cultivate, the challenges these plants face, and suggestive measures to enhance APV's adoption and impact in the country.

Region Selection

Choosing the right region for APV is essential to maximize the efficiency of APV systems. Regions with high solar irradiation, abundant agricultural land and a significant reliance on

TABLE 2.1

APV Potential in India: Top Regions and Methodology for Identifying Optimal Locations

Most Suitable Regions for APV
According to the report Agrivoltaics in India, the methodology for estimating the potential of APV in India follows a systematic approach, incorporating several key factors to assess the suitability and capacity for APV systems across different states. The first step involves resource identification, where solar resource availability is analyzed at the district level. This includes studying solar irradiance data to gauge the solar energy generation potential in various regions. Next, Geographic Information System (GIS) restriction criteria are applied to identify suitable land for APV installations. This involves technical constraints such as ensuring plants' proximity to substations (within 25 km), roads or railways (within 10 km), sufficient Solar Global Horizontal Irradiance (GHI) levels (above 4.5 kWh/m²/day), and appropriate land slope (less than 8 degrees). Once these criterions are established, solar resource data is overlaid on GIS maps, allowing for a visual assessment of regions that meet these technical requirements, identifying the most promising locations for APV projects. The western and north-western regions in states like Maharashtra, Rajasthan show strong potential for APV adoption, offering significant opportunities for integrating solar energy with agriculture (Jain et al., 2024).

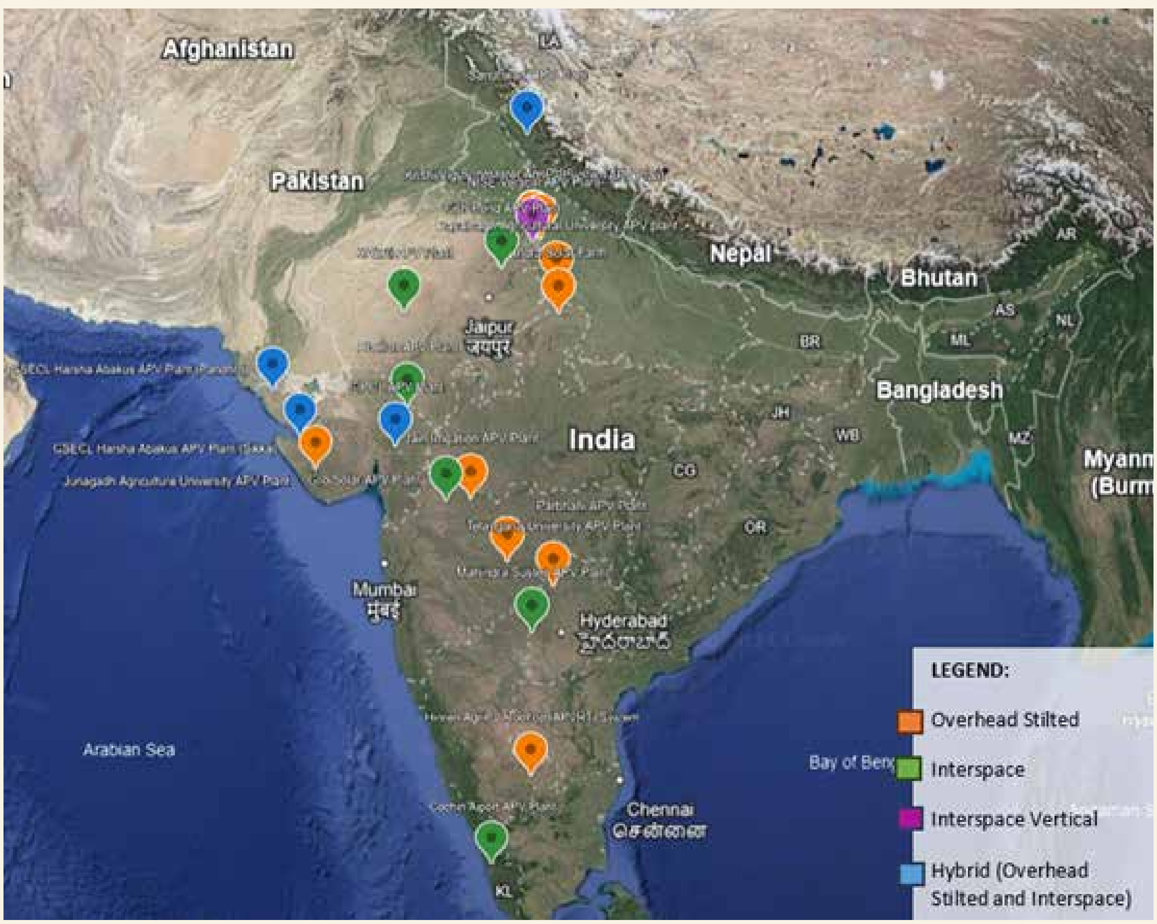
agriculture for economic growth are ideal candidates. This considers the diverse crop portfolio, including shade-tolerant crops that thrive under the partial shading provided by solar panels. **Table 2.1** discusses a possible approach that can be considered during the region selection of implementing APV in the country.

Overview of APV Plants in India

The pilot projects are experimental platforms where feasibility tests and performance optimization of integrating solar photovoltaic (PV) systems with agriculture are conducted. Through such pilot projects, key stakeholders gain insights into the economic viability of APV under varying cropping patterns. Such projects determine the crop-location pairings and the suitable APV technology. This is important for the extensive adoption of APV in India. As of 2023, there are around 21 operational APV sites in India. Additionally, there are 3 upcoming pilot projects. These operational pilot projects are concentrated mainly in the western region in states like Gujarat and Maharashtra flowed by northern region including states of Rajasthan, Delhi-NCR area and western Uttar Pradesh and southern region including states of Karnataka, Kerala, Andhra Pradesh, and Telangana with small number of plants being operational there. The majority of the APV pilots are commercial pilots, followed by R&D or academic plants and government-supported pilots. **Figure 2.1** shows the approximate location of the chosen APV pilot sites

FIGURE 2.1

Location of APV Pilots

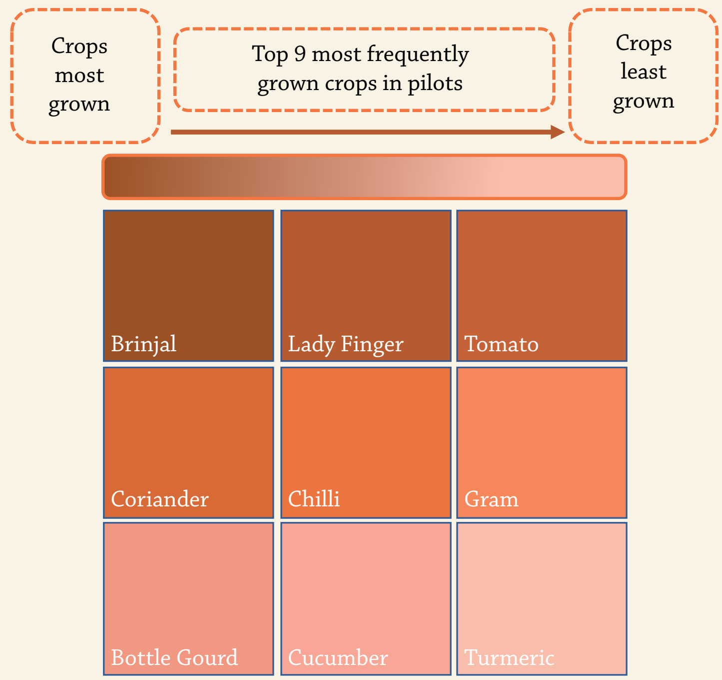


Source: Google Earth, IGEF and NSEFI, 2023.

In these pilot APV plants, approximately 50 to 60 types of horticultural crops are being cultivated, including vegetables, fruits, flowers, spices, and herbs, out of which the top 10 crops are illustrated in **Figure 2.2**. Brinjal and lady finger dominate, being grown in most of these plants. This is followed by tomato and coriander. In contrast, staple crops like wheat and rice have minimal popularity, indicating that APV adoption for these major crops in India have shown limited success (IGEF and NSEFI, 2023).

FIGURE 2.2

Popular Crops Grown in Existing APV Plants in India



Source: Indo-German Energy Forum (IGEF) and National Solar Energy Federation of India (NSEFI).

Challenges of APV in India

The adoption of APV in India will enhance renewable energy generation while supporting agricultural productivity. However, several financial, technological barriers and environmental and regulatory hurdles hinder the widespread implementation and adoption of such technologies. These are shown in **Figure 2.3**.

Some of the solutions to the key challenges can be to mainly address the financial, tech-

FIGURE 2.3

Challenges of APV in India

Lack of Financial Incentives

- High CAPEX for setting up APV systems makes it unaffordable for many farmers, particularly smallholders.
- Potential yield reduction increases the financial risk.
- Current subsidies and feed-in tariffs are insufficient to encourage adoption (Balchandani, 2024).

Inadequate Infrastructure and Technology

- High installation costs and expensive components hinder adoption.
- Lack of knowledge, training, and maintenance skills are barriers to APV implementation (IGEF and NSEFI, 2023).

Land Conversion

- Using agricultural land for solar projects requires formal conversion in some states, deterring farmers.
- Farming's cultural and economic importance makes farmers reluctant to participate in APV projects.

Stakeholder Coordination

- Lack of collaboration between partners hampering APV's growth. (Balchandani, 2024)

Environmental Factors

- Solar panel shading can disrupt local ecosystems, affecting both crop growth and fauna.
- Soil degradation and water management challenges arise, including soil compaction and increased runoff.

Source: Author's Own.

nical, environmental and stakeholder-related issues.[2]

- Lack of Financial Incentives: To address high CAPEX, governments can provide larger subsidies or incentives, especially to smallholders. Financing models like low-interest loans and public-private partnerships can help reduce financial risks while revising feed-in tariffs and payback rates.
- Inadequate Infrastructure and Technology: Upgrading infrastructure and reducing utility rates can encourage adoption. Education and training programs for farmers and technicians can enhance the skills needed for APV installation and maintenance. Innovative designs with different orientations, better electrical infrastructure equipment and integrated systems can improve the efficiency of the APV system.
- Land Conversion: Simplifying land conversion rules for APV projects and promoting dual-use land policies can minimize bureaucratic hurdles. Raising awareness about the benefits of APV can overcome cultural and economic resistance from farmers.
- Stakeholder Collaboration: Establishing a platform for collaboration among farmers, developers, and policymakers can improve coordination.
- Environmental Factors: Designing APV systems with adjustable or elevated panels can balance solar energy generation with crop health. Implementing soil management practices like mulching and no-till farming will prevent soil degradation.

Conclusion

Integrating APV in India offers a promising solution for enhancing both energy generation and agricultural productivity. However, successful implementation relies on careful region and crop selection suitable to local conditions, as seen in pilot projects. In addition, there are significant financing, technology, and land conversion challenges. While pilot projects across various states are experimenting with a variety of crops, particularly horticultural crops, there is a need to explore the compatibility of other staple crops. Also, there is a need for greater collaboration among stakeholders, further financial support, and targeted efforts to make APV systems accessible and viable for smallholders. Addressing these issues through policy reforms is critical. Chapter 2's insights transition into Chapter 3, which examines the PM-KUSUM scheme—India's key initiative for solarizing agriculture. Scaling APV requires a thorough understanding of the current policy landscape and identifying necessary modifications to ensure the successful integration of this innovation into Indian agriculture.

2. Refer to Chapter 6 of this report for detailed Policy Recommendations.

Integrating APV into PM-KUSUM

3

Overcoming Barriers for Sustainable Agriculture and Farmers' Livelihood Augmentation

Subhodeep Basu

Introduction

APV within the PM-KUSUM scheme offers a promising avenue to boost Indian agriculture by merging solar energy generation with traditional farming and enhancing farmers' incomes. Despite progress in solarizing agriculture, PM-KUSUM faces challenges like high capital costs, complex financing, and restrictive land-use regulations that hinder APV scalability. Thus, it is imperative to recognize the challenges faced by KUSUM to ensure that APV's scale up if done through KUSUM does not face any impediments. APV aligns naturally with Component A of PM-KUSUM, allowing systems of 500 kW to 2 MW to be established by farmers, cooperatives, or third-party developers, including DISCOMs. Under Component B, APV can enhance the business case for farmers installing standalone solar pumps by enabling simultaneous crop and energy production, making it beneficial for smallholder farmers with limited land. Crop suitability remains crucial in both cases. In this chapter, the achievements and limitations of PM-KUSUM have been discussed to unearth the possibilities of effectively integrating APV within the ambit of KUSUM. It has also focussed on innovative business models like farmer-developer partnerships to overcome barriers and unlock APV's full potential as a sustainable solution for agriculture and renewable energy in India.

PM-KUSUM: Shining a Light on Indian Agriculture

The PM-KUSUM was launched in 2019 to solarise Indian agriculture for farm income augmentation through harvesting an additional crop, i.e., the sun. While the scheme has made strides in promoting solarization, it faces significant challenges such as high capital costs, complex financing, and restrictive land-use regulations. PM-KUSUM already has provisions for implementing APV. **Figure 3.1** shows a solar PV plant in India.

It has three components to support farmers as shown in **Figure 3.2** Component A targets farmers or farmer collectives to set up solar power plants in their barren fields or lease land to developers to do that. Component B is for reducing the heavy diesel dependency by enabling small farmers to replace diesel pumps with stand-alone off grid solar irrigation pumps. The third component allows the solarisation of individual grid-connected pumps (IPS)[3] or an entire feeder (FLS). The key word here is "grid," as this model and Component A allows farmers to evacuate surplus energy to the grid to earn an additional income based on the feed-in tariff decided by the SERC. Over 4.11 lakh farmers have benefitted from PM-KUSUM as of July 2024 (MNRE, 2024).

3. IPS- Individual Pump solarization; FLS- to Feeder Level Solarisation.

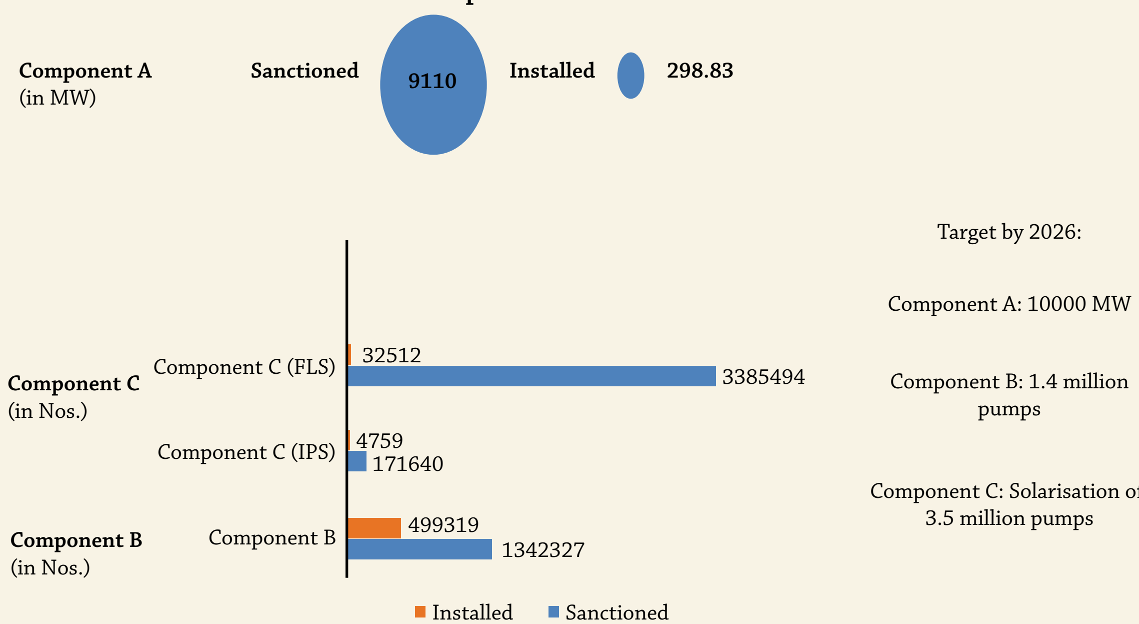
FIGURE 3.1

Solar PV Plant in India

Source: International Water Management Institute (IWMI).

FIGURE 3.2

Components of PM-KUSUM



Source: PM KUSUM Portal, MNRE.

PM-KUSUM scheme also caters to DISCOMS. Government reports suggest that 11 of the country's biggest DISCOMS are powering 95% of the electricity consumed in agriculture. This comes with a hefty price tag — over Rs one lakh crore annually in electricity subsidies drawn from the State's exchequer (PM-Kusum: A New Green Revolution, 2020). By enabling the farmers' switch to solar instead of subsidised electricity, PM-KUSUM provides relief to the fiscal performance of the country's DISCOMS.

Implementation Barriers in PM-KUSUM

PM-KUSUM is a much-lauded step towards a cleaner future and is a crucial tool for farmers' income augmentation. One of the first beneficiaries of PM-KUSUM in Rajasthan earns approximately Rs 4 lakh a month from the 1 MW plant set up through PM-KUSUM's Component A (DTE, 2021). This is his income from energy sales as crop income from the same plot of land is not being considered. Integrating his crop income would enhance his income with a substantial reduction of his pay-back period. These are remarkable success stories of PM-KUSUM but the overall performance of this scheme has been less than satisfactory and is heavily skewed towards four states only[4], with Rajasthan and Maharashtra being the pioneers, covering almost 50% of the total beneficiaries under the scheme.

The comprehensiveness of the scheme in terms of its design and objectives is not yet reflected in its implementation. As on September 2024, Component B has performed well, since over 13 lakh pumps have been sanctioned, out of which 37.1% have been installed; Component A and Component C are way off their targets in terms of sanctioned and installed numbers. Only 298.83 MW has been installed under Component A against a sanction of 9110 MW, while under Component C, only 2.77% and 0.96% have been installed against the total sanctioned pumps under IPS and FLS, respectively (MNRE, National Portal- PM-KUSUM, 2024). While the installation is picking up pace, financial and institutional factors are critical roadblocks for the poor performance of Component A and Component C. A reason cited is the state's reluctance to contribute to fund in the initial phases (Goel & Rahman, 2022). This stems from some states providing free/subsidized power, so there is no rationale for increasing the liability by paying an additional feed-in tariff. For example, in Haryana, the subsidy for agriculture electricity stands at roughly Rs 5000 crore. Considering that a large number of such connections are unmetered, it is difficult to arrive at the appropriate amount incurred in farm power subsidy. From the farmers' point of view, the majority are receiving free or highly subsidized power and have low incentives to invest in the high capex of acquiring solar pumps. Apart from the farmers' reluctance in investing owing to high capex, it is reported that in areas where water table is very deep and the major crop is paddy (as in the case of Punjab), farmers prefer electric pumps over solar pumps of similar capacity due to their higher discharge. In Punjab's scenario farmers receive electricity for agriculture at no cost, with power supplied in eight-hour cycles. There is also fairly reliable access to canal water provided at a weekly schedule (Yadav & Khanna, 2024). The availability of free power and alternative irrigation management techniques makes farmers less inclined towards adopting solar-powered water pumps.

Farmers face issues in financing these components through institutional lenders. While Component C and Component B provides a 60% subsidy (30% CFA and 30% State), Component A has no subsidy component. Farmers and developers rely on loan assistance to implement this since a 1 MW plant costs approximately Rs 4-5 crores. Banks are hesitant to disburse loans due to developers'/farmers' insufficient collateral limiting their ability to secure the required funding (Rahman, et al., 2023). For farmers and developers, the option of paying the upfront cost as instalment could have been effective. In the absence of financial institutions support and favourable financing options in the scheme, the progress of PM-KUSUM is hindered.

The other hurdles in project implementation are land identification for solar plants, restrictions in land leasing and land-use regulation. Developers (in Component A or Component C) face issues in identifying and leasing affordable land for setting up a power plant. This is due to asymmetry of information between farmers and developers owing to interaction barriers between the two entities. These interaction barriers exist because farmers interested in adopting solar pumps or leasing land for solar plants don't know whom to approach. There are land leasing and land-use regulations challenges.

4. Rajasthan, Maharashtra, Uttar Pradesh, Haryana make up 82% of total beneficiaries in KUSUM (MNRE).

"Land" is a state subject and land regulations vary from state to state. There are procedural difficulties in land-use conversion from agriculture to non-agriculture use.

Another impediment is the offered feed-in tariff (FiT) decided by State regulatory bodies that developers find commercially non-viable for decentralised solar plants (Rahman, Agarwal, & Jain, 2021). Setting a tariff that covers the risks and efforts of developers/farmers will ensure commercial viability of solar plant models. Multiple studies have reported that the developers feel that the tariff calculations need to be revisited and should reflect the true cost incurred on decentralised solar plants. At present, FiT is determined by the State Electricity Regulatory Commission (SERC). Discussions with private developers revealed that the FiT fails to reflect the actual O&M costs, the capital cost and logistical overheads of distributed solar plants, limiting the developers' interest in the scheme. Every State has a uniform FiT decided by their respective SERC. Thus, within a state where land values differ substantially, the FiT would be the same. States in such situations could consider refining their tariff calculations through prior consultations with farmers' and developers to make them responsive to evolving market dynamics and differing land values.

Enhancing Farmer Income through APV: Overcoming Challenges in PM-KUSUM

Currently KUSUM's Component A has been restricted to barren lands in Rajasthan where value of land is usually low.[5] Restricting APV to unproductive land prioritizes energy generation over agriculture, undermining the farming component. To strike the right balance between "agri" and "voltaics" in accelerating APV in the country, a dynamic approach is needed. One way of achieving that is through the development and testing of different business models of APV under different geographical contexts. These business models would allow defining farmers' and other key collaborators' stakes and opportunities within APV.[6]

Business Models to scale APV in India

- **Model A: Partnership arrangement between Farmer and Developer**

In this business model as illustrated in **Figure 3.3**, farmer and developer would co-design and co-develop the system with both having a stake in it. The farmer is compensated by the developer for the land loss due to photovoltaics while he would enjoy ownership over his land during the project tenure. The developer would take the lead in managing the energy generation and the receipts from energy sales. Such models could be prioritized in areas where land is productive for agriculture, and markets for high-value crops are readily available as in peri-urban areas. Farmers can grow high-value crops that thrive under partial shading, augmenting their income. Such peri-urban areas with good market linkage would fetch a high land rent. It will allow farmers to augment their income through the land rent while developers can manage energy generation and receipts from it. The clauses of such arrangements should be made clear to all stakeholders to avoid any conflicts. Such a model could take off where farmers are entrepreneurial and are willing to experiment with high-value crops suitable to grow under shading.

- **Model B: System wholly owned and operated by one entity (A Farmer, A group of Farmers or an individual Developer)**

In model B as illustrated in **Figure 3.4**, the entire system is owned and operated by a single entity, be it a developer, an individual farmer, or a group of farmers (FPO). The focus is to maximize the net revenue from the land through a mix of energy generation and agriculture. For the developer-owned systems, farmers benefit from receiving land rent and if the system is owned by farmers, the land rent can be eliminated that reduces the overall profitability.

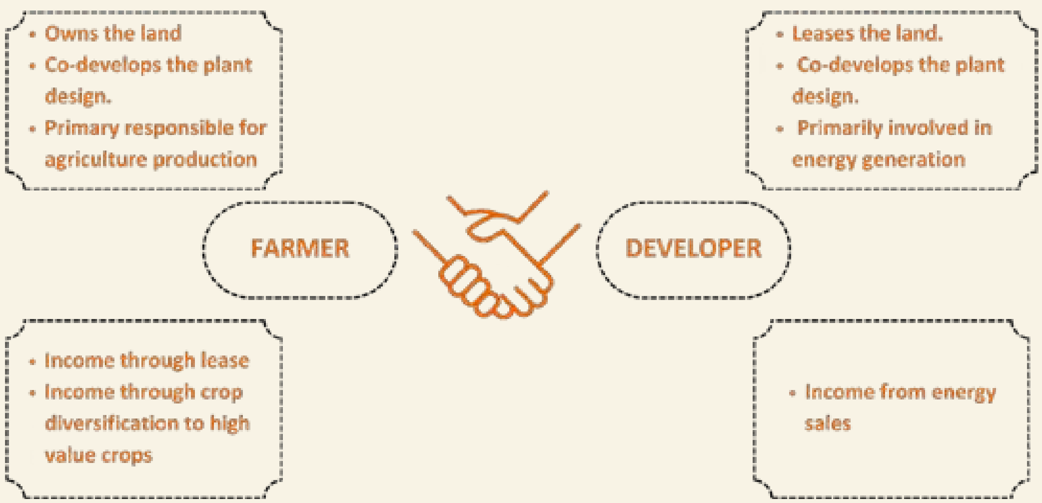
This model is suited for entrepreneurial individuals or groups interested in diversifying

5. Rajasthan alone accounts for 78% of the total installed capacity under PM-KUSUM Component A (PM-KUSUM Portal).

6. The models discussed are referenced in the report "Agrivoltaics in India: Challenges and Opportunities for Scale-Up," IISD, 2023.

FIGURE 3.3

Model A: Partnership Arrangement between Farmer and Developer



Source: Compiled by Author.

FIGURE 3.4

Model B: System Wholly Owned and Operated by One Entity

Source: Compiled by Author.

their income beyond conventional farming and in peri-urban areas that have strong markets for high-value crops. The system's design is revenue-driven, leveraging shading benefits to enhance crop growth in semi-arid areas and allows for flexible crop management to optimize crop productivity. In most cases, it could be private developers who own these systems due to affordability issues for farmers. However, such private entities could lack the expertise of remunerative agriculture practices. Thus, there is a potential risk that under such models (if not owned by an individual farmer or farmer groups), agriculture activities could be deprioritized, especially if power generation is more profitable. Unlike Model A where farmers have a considerable stake in decision-making and the design of the plant, in Model B private developers decide about agriculture practices and energy management aspects (for private developer-owned systems).

- **Model C: Developer as a primary promoter, farmer as a partner**

In model C as illustrated in **Figure 3.5**, developer acts a promoter and farmers are the partners. Farmer is responsible for managing the agricultural system while utilising the land for cultivation. This helps farmers to access uncultivated land and expand their agricultural opportunities. Developers in this model would need to design the project with specific modifications regarding panel elevation and spacing to support the agricultural activities. It is important to note that in such a model, agriculture is a supporting activity while energy sales are primary as the system is owned by developer and operated by both developer and farmers. Unlike Model A, such models are considered for arid and semi-arid region where land productivity and land value are low. Such a model would involve lower upfront capital investment, making them more affordable for developers. From a farming point of view, such models would be beneficial for landless farmers since it would help them cultivate someone else's land for livelihoods augmentation. The success of the model depends on the developer's willingness to make necessary design modifications to support agriculture that may or may not always be prioritized.

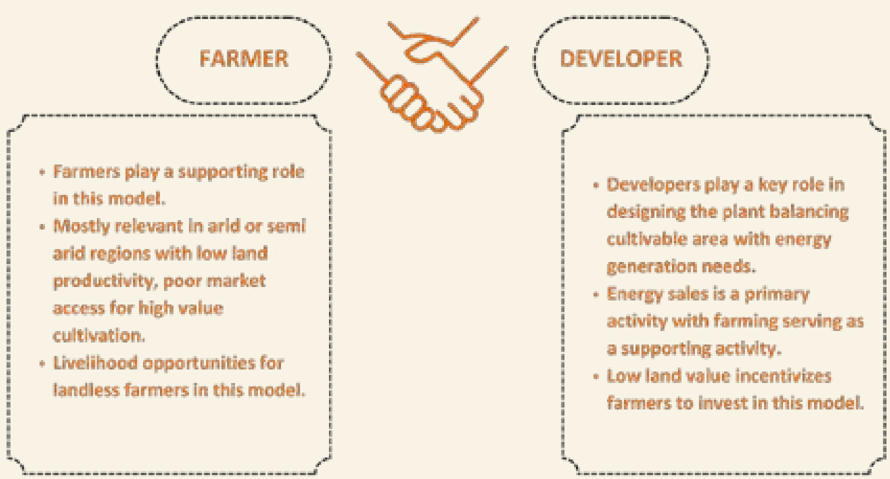
Conclusion

APV represents a promising solution to address India's energy and agricultural challenges, offering a pathway to augment farmers' income while advancing the country's clean energy goals. PM-KUSUM, a key government initiative, has provisions for APV under its Components A and C, and early-stage discussions have been initiated to test APV solutions through workshops and stakeholder consultations. However, to unlock APV's full potential, critical roadblocks must be addressed, and a robust policy framework is needed to support its growth.

One of the primary challenges facing APV under PM-KUSUM is the high capital expenditure (capex), which is at least 1.5 times more than that of typical ground-mounted solar installations. This cost disparity is due to the unique design requirements of APV, such as elevated panel structures that facilitate agricultural activities underneath. To offset these additional costs, the existing FiT needs to be revised; otherwise, APV projects will remain financially burdensome. The absence of specific guidelines distinguishing APV from conventional ground-mounted systems—such as minimum panel height and the percentage of land to be reserved for agricultural use complicates the situation. A clear definition of APV standards would help streamline its implementation and ensure that agricultural priorities are not compromised.

FIGURE 3.5

Model C: Developer as a Primary Promoter, Farmer as a Partner



Source: Compiled by Author.

Land use regulations also pose a significant barrier to APV adoption. Currently, PM-KUSUM's Component A is confined to barren lands, particularly in Rajasthan, where the low land value makes solar installations more feasible. However, restricting APV to unproductive lands undermines its potential to enhance agricultural productivity alongside energy generation. For APV to thrive, policies must accommodate diverse land types, ensuring that agricultural benefits are not side lined in favour of energy management.

Private sector consultations reveal that PM-KUSUM, in its current structure, does not adequately support the distinct needs of APV. High capex, regulatory complexities, and a lack of targeted financial mechanisms hinder its adoption. A separate or modified policy framework tailored for APV could address these issues by providing farmer-centric financing options, revising FiT rates, and incorporating learnings from the existing KUSUM components.

Ultimately, APV can play a pivotal role in addressing the growing land constraints posed by India's expanding solar capacity needs. By allowing dual land use, APV can cater to the irrigation, food, and energy demands of farmers, creating additional income opportunities and enhancing rural livelihoods. For APV to succeed, cohesive policies that address financial, regulatory and technical challenges are essential. With government support for innovative business models and a commitment to refining existing frameworks, APV can transform India's agricultural and energy landscape, driving a sustainable future that balances food security, energy sustainability, and farmer prosperity.

4

Economic Feasibility of APV

Soham Roy, Subhodeep Basu and Saksham Gupta

Introduction

Solar energy is land-intensive, with a typical solar PV project requiring between 3.5 to 7.5 acres/MW of land (TERI, 2017). A recent scenario modelling of India's net-zero transition pathways finds that India would need a cumulative solar and wind capacity of about 7400 GW to achieve a 2070 net-zero target (Chaturvedi and Malyan, 2021). These and other power generation assets combined could take up about 4.9 to 6.1 percent of the total land area by 2100.

India is primarily agricultural, with about 60 percent of its total land under cultivation (World Bank, 2024). Therefore, agricultural land has to be converted or otherwise transferred for the construction of solar power projects. This could involve leasing/selling the land to developers to produce solar power or farmers constructing solar plants on their own land. If agricultural production is co-located with solar power production, income is boosted, and India's food security would be unharmed while contributing to the energy transition.

As per the Situational Assessment Survey of 2018-19, the average monthly household agricultural income is estimated at Rs. 10218. "Doubling of Farmers Income (DFI)" has been one of the priorities for the Government of India, and it has implemented several schemes for that. In this context, examining the effect of co-locating solar and agriculture (APV) on farmers' economic outcomes is critical. In this chapter, we will investigate the economic feasibility of APV systems under varying assumptions of design systems and tariffs and the increase in farmer's incomes.

Augmenting Farmer's Incomes

For this analysis, we surveyed secondary reports on the subject and interviewed several stakeholders (developers, farmers, etc.). As mentioned earlier, the farmers could construct the plant at their expense or lease/sell it to a developer for the same. If the developer acquires/leases the land, they can cultivate the land themselves or the farmers could continue the cultivation of the land. In our case study of Sunmaster Systems 2.5 MW APV in Najafgarh, Delhi, we found that the developer cultivates the land and generates solar power in exchange for an annual rent of Rs 1 lakh/acre to the farmer.

This is economically advantageous for the farmers, given that the pattern of production on the land has changed following the installation of the PV system. Crops such as turmeric, potato, tomato, and brinjal are commonly grown under the shading. These crops (refer to **Table 5.1**) provide four times more income than those grown before land transfer (wheat, mustard). The lease rent is more than twice the agricultural income earned before the APV was set up. The farmer's lack of know-how about the crops presently grown (turmeric in particular) prevented them from cultivating these crops on their own. These factors influenced the farmer to lease out the land instead of cultivating it.

TABLE 4.1

Income from Crops

Name of the Crop	*Cultivator*	*Area Under Cultivation under the APV (Acres)*	*Quantity Produced (Kg)/Acre*	*Price (Rs./kg)*	*Income (Rs)*
Turmeric	Developer under PV	4	1100	₹ 140	₹ 6,16,000
Potato	Developer under PV	1	3000	₹ 20	₹ 60,000
Wheat	Farmer in separate land	2	2000	₹ 20	₹ 52,000
Mustard	Farmer in separate land	2	1100	₹ 60	₹ 1,12,000

Source: Compiled by Author based on discussion with farmer on whose land the APV Plant has been set up at Najafgarh.

TABLE 4.2

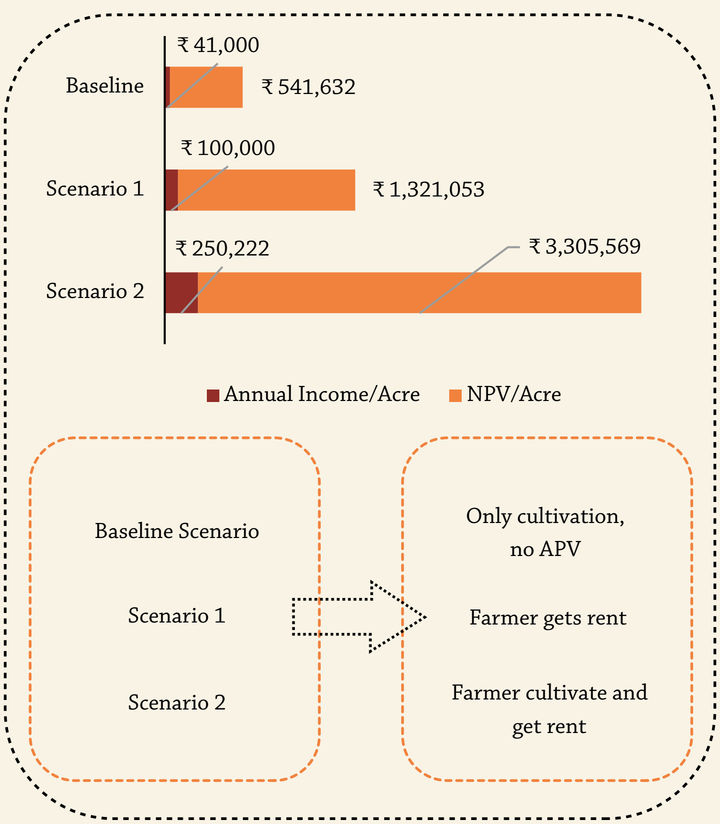
Crops Grown in 2 Scenarios

Scenario	*Land under only Cultivation (Acre)*	*Land under APV(Acre)*	*Crops Grown*	*Cultivation Done by*
1	4.5	0	Wheat, Mustard	Farmer
2	0	4.5	Turmeric, Potato	Developer
3	0	4.5	Turmeric, Potato	Farmer

Source: Author's Own.

FIGURE 4.1

Farmer's Income in 2 Scenarios



Source: Author's Own.

In **Table 4.1** below, we have provided the crop-wise income data collected from the field.

As seen above, the developer cultivated turmeric and potato in the APV plant's shading area. The farmer cultivates wheat and mustard on land owned by them. At present, the farmer's income from the APV plant is restricted to the land rent of 4.5 acres.

For our analysis, we consider a hypothetical scenario where the farmer cultivates the land under the shading of the APV plant and generates income from it in addition to earning rent. We compare this hypothetical income as well as the real income at present to a baseline scenario where no APV plant exists, and the farmer cultivates wheat and mustard in the 4.5 acres of land. The results are given in **Table 4.2**.

The income generated by the farmer in two scenarios is described in **Figure 4.1**.

In the baseline scenario, the farmer's income is minimal as the APV plant does not exist, and he cultivates wheat and mustard. In this scenario, the annual income is 41000 INR/Acre, and the NPV over 27 years at a discount rate of 6% is over INR 5 lakh.

In scenario 1, an APV plant is installed, and the developer cultivates turmeric and potato in the shading area. The farmer receives a rent of 1,00,000 INR/Acre for 4.5 acres per year. The NPV over 27 years comes out to be 13,21,053 INR/Acre. Therefore, the farmer's income multiplies close to 2.5 times that of the baseline scenario.

In the hypothetical scenario 2, the farmer cultivates turmeric and potato in the shading area and earns agricultural income in addition to rent. Here, annual income increases to over INR 2.5 lakh per acre. Farmer's net present value over a period of 27 years, considering a discount rate of 6%, is over INR 33 lakh per acre. Hence, the farmer's income has multiplied over six times that of the baseline scenario.

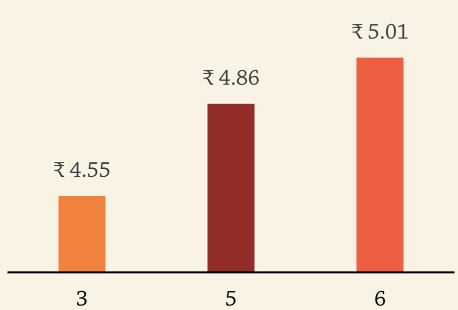
All the calculations that follow, assume the developer owns the solar plant and cultivates the land. The farmer gets a rent for leasing out the land but is not involved in cultivation. This is based on consultations with relevant stakeholders surveyed in the field.

Economic Feasibility of the APV

Our discussions allowed us to understand qualitatively and quantitatively the cashflows during the project's lifecycle. For instance, for a 1 MW solar plant built at a mounting height of 3 meters, about INR 4.5 crore upfront capital is required. This cost includes modules, mounting structures, balance of plant costs, and other ancillary charges. This cost varies with the design, structure height, and module type in use. **Figure 4.2** illustrates the variation.

FIGURE 4.2

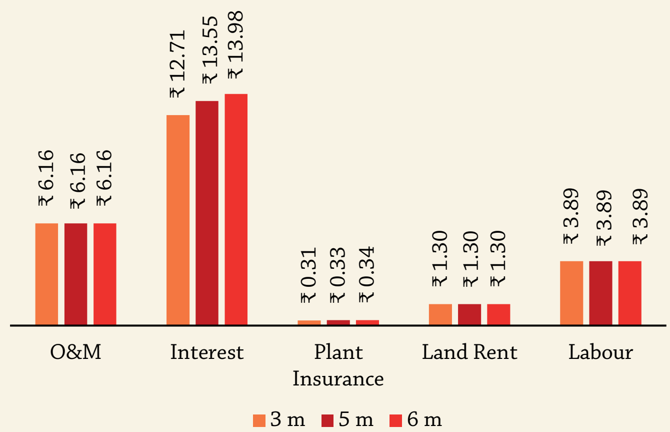
Capex (INR Crores/MW) vs Mounting Structure Height (m)



Source: Author's Own.

FIGURE 4.3

Opex (INR Crores) for a 2.5 MW Plant Over 27 Years with Varying Mounting Structure Height(m)



Source: Author's Own.

Of the total capital cost, developers (or farmers) use a combination of debt and equity instruments. As per the survey and discussions with developers, equity constitutes 30% of the total capital expenditure, and loans from the bank fund the remaining capital cost. For our analysis, we considered an interest rate of 8.5% and a loan repayment period of 7 years, which mirrors our field observations.

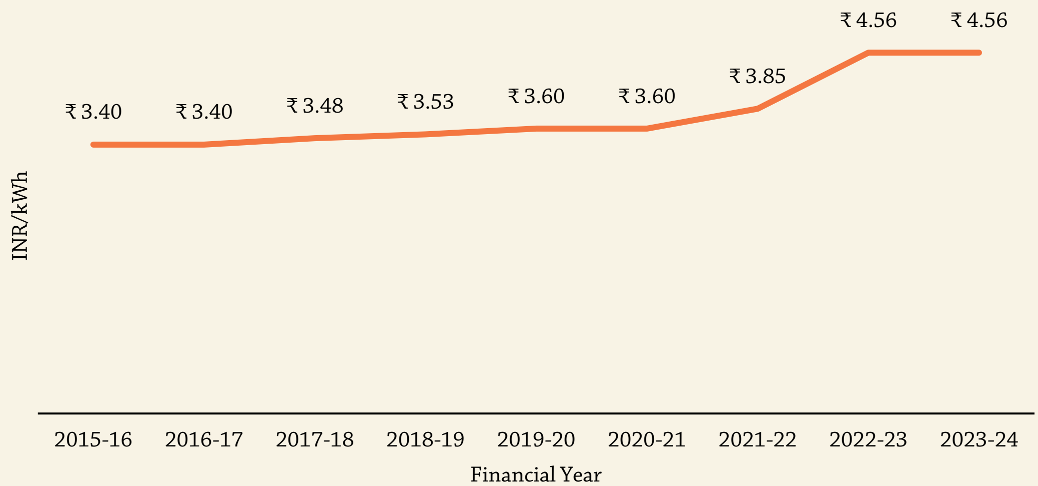
During the plant lifecycle, costs are incurred in operation and maintenance, labour costs, rent to the farmer, interest payment to the bank, etc. For the 2.5 MW Sunmaster plant, an approximate breakdown of operational expenditure over 27 years lifecycle is given in **Figure 4.3**.

The economic feasibility of the APV system depends on the revenue generated by the power plant throughout its lifecycle, which depends on the tariff charged on solar power generated. Usually, developers supply power at a tariff as per the Power Purchase Agreement (PPA) signed with DISCOMS or private consumers.

We have considered the system's feasibility under several scenarios for our analysis. As per the Sunmaster APV survey in Najafgarh, the tariff was Rs 5.1 per unit. As per secondary reports, the average tariff for utility-scale systems in India is assumed to be 2.65 Rs/kWh. Component A of the PM-KUSUM scheme was designed to augment farmers' income by

FIGURE 4.4

APPC for Thermal Power (National Level) (INR/kWh)



Source: Author's Own.

installing grid-connected PV systems on previously cultivated land. Based on publicly available reports, the tariff for PM-KUSUM Component A is assumed to be 3.25 Rs/kWh[7].

A state distribution utility can buy power from multiple sources. Since thermal power constitutes the largest percentage of India's installed capacity, it is interesting to see whether APV systems will remain economically feasible at the average power purchase cost (APPC) of thermal power. **Figure 4.4** demonstrates the trend in APPC thermal power in the last few years. The average power purchase cost of thermal power is 4.56 Rs/kWh.

Economic feasibility is tested at 15% and 20% increment of thermal APPC. Overall, we test for the following scenarios as shown in **Table 4.3**. In addition, we consider the average tariff over 27 years assuming a yearly tariff escalation of 3%.

We ascertain the difference in the plant's commercial viability in case agricultural production is not carried out and if the mounting structure of the plant varies. The mounting structure cost constitutes about 10% of the Capex cost, and it increases with increasing height. The analysis is done with a discount rate of 6%. The results of the analysis are discussed in **Figure 4.5**.

TABLE 4.3

FiT Scenarios Modelled

FiT (Description)	*FiT (INR/ Unit)*	*FiT post Escalation (INR/Unit)*
FiT as per Current Ground Mounted APPC (Assumed)	2.65	4.00
PM KUSUM Component A	3.25	4.90
FiT as per Current APPC of Thermal Power	4.56	6.88
FiT as per Actual APPC as per Current PPA	5.1	7.69
FiT as per 15% Premium on Thermal Power	5.24	7.90
FiT as per 20% Premium of Thermal Power	5.47	8.25

Source: Author's Own.

At 3 meters of mounting structure height, the Internal Rate of Return (IRR) and Payback Period for the APV plant are given below.

Over the lifecycle of 27 years, we see that with increasing tariffs, the IRR of the APV Project

7. This is based on the tariff of PM Kusum component A in Rajasthan, since Rajasthan has commissioned the highest share of solar projects under the program. For recent tariffs see, https://www.mercomindia.com/rajasthan-regulator-approves-tariffs-for-solar-projects-under-kusum

increases, and as a result, the payback period reduces. IRR is more significant when agricultural production occurs alongside solar power production, which shows that the APV systems augment agrarian income. At the tariff of 2.65 Rs/kWh (usually provided to utility-scale solar), we see an IRR of 5%, which is lower than the discount rate of 6% we have considered for our analysis. Under this setting, the APV system becomes feasible at the PM KUSUM Component A tariff of 3.25 Rs/kWh when it provides an IRR of 9% and a payback period of 13 years.

The same analysis is repeated for an APV system with a mounting structure height of 5 meters. The results are illustrated in **Figure 4.6**.

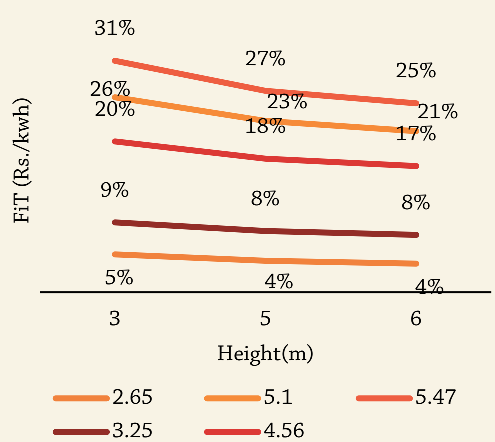
Again, we see that agricultural production augments income obtained from the sale of solar power. The system becomes feasible at the tariff of 3.25 Rs/kWh with an IRR of 8% and a payback period of 14 years. For the Sunmaster APV system, the actual tariff of 5.1 Rs/kWh would give an IRR of 18% and a payback period of 10 years.

The insights remain unchanged for the plant with a height of 6 meters. This is given in Appendix Section B.

The following trends become clear so far as the economic feasibility of APV plants is considered. First, with the increasing height of the mounting structure of the APV plant, IRR has a downward trend that adds to the capex. This is illustrated in **Figure 4.7**.

FIGURE 4.7

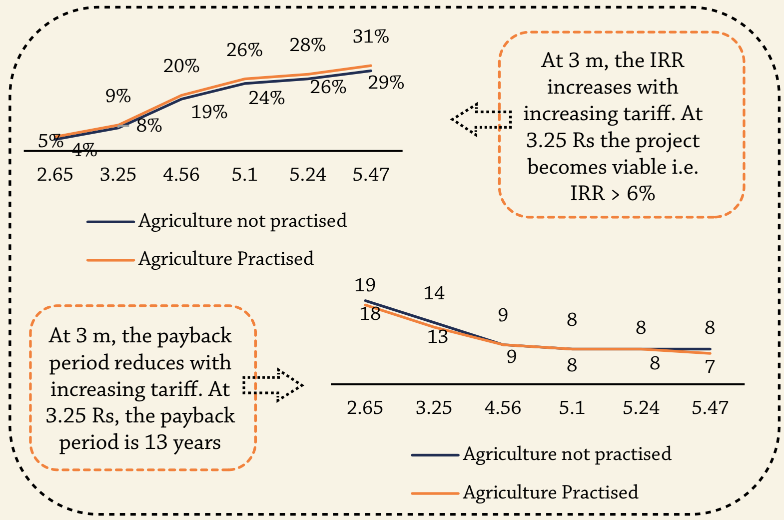
IRR (%) Decreasing with Increasing Mounting Structure Height with Varying Tariffs



Source: Author's Own.

FIGURE 4.5

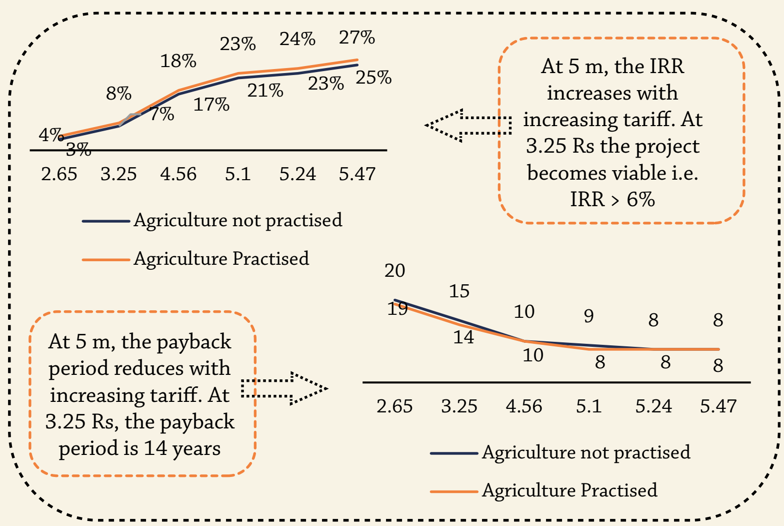
IRR and Payback Period of a 3-meter APV System with Varying Tariffs



Source: Author's Own.

FIGURE 4.6

IRR and Payback Period of a 5-meter APV System with Varying Tariffs



Source: Author's Own.

Secondly, APV augments agricultural income under all scenarios compared to a simple PV system built on agricultural land. Thirdly, under all design conditions, the tariff must resemble the PM KUSUM Component A tariff, i.e., 3.25 Rs/unit. Therefore, APV systems need a tariff higher than that of utility-scale solar to be economically feasible; however, this tariff is substantially cheaper than APPC of thermal power. Therefore, APV systems are more profitable than thermal power at the same tariff of 4.56 INR/kWh, while remaining feasible at a lower tariff. Thus, APV systems offer a much more affordable solution to DISCOMs .

Conclusion

From the developer's perspective, APV is a lucrative proposition. In the scenarios laid out in this chapter, developers breakeven their investment between 10 to 15 years. This is dependent on the tariff structures offered by the DISCOM. Our study demonstrates the direct proportionality between tariffs offered and the returns for the developer. Public DISCOMs in India are under financial stress (Das and Srikanth, 2020). Therefore, there is room for research into optimizing the tariff structures so that APV remains economically feasible while not being a fiscal burden on state utilities.

This chapter demonstrates the potential of APV systems to augment farmers' incomes, and we can conclude that solar power can emerge as the third crop. Our case study shows that APV systems can augment farmer's incomes from anywhere between 2 to 6 times. However, a more comprehensive study of this possibility is required. This analysis should account for all possible permutations and combinations of design structures, agroclimatic conditions, crops, and business models. This would provide us with a granular understanding of the extent to which farmer's income can increase under all possible scenarios. Given the widespread recurrence of land-use conflicts and dwindling incomes from agriculture, APV can emerge as an all-encompassing solution as long as it is an economically viable model for three major players, i.e., farmers, DISCOMs, and private players.

The assumptions and analysis for this chapter is added in Appendix B.

Empowering India's Farmers Through Solar Cooperatives

Harnessing Renewable Energy for Agricultural Innovation and Sustainability

5

Subhodeep Basu

Solar Cooperatives as Farmer-Centric Solutions: *The chapter highlights the potential of solar cooperatives as farmer collectives that can help reduce irrigation costs, enhance income through energy sales, and improve solar adoption rates by pooling resources and leveraging collective bargaining power.*

Case Study of SPICE in Dhundi, Gujarat: *It discusses the world's first solar cooperative, SPICE, where small farmers collectively own solar pumps, sell surplus energy, and earn additional income, showcasing the benefits of cooperative models in reducing diesel dependency and enhancing livelihood outcomes.*

Scaling APV through Farmer Collectives: *The chapter argues that farmer institutions like cooperatives and Farmer Producer Organizations (FPOs) are crucial for scaling APV in India, advocating for policy support to enable these groups to invest in innovative solar-agriculture models that can boost productivity, sustainability, and farmers' incomes.*

Introduction

The Indian solar energy market is expected to grow substantially, with a CAGR of 19.80% from 2024 to 2029[8]. To ensure that agriculture reaps the benefits of this growth, it is important to have farmer-centric institutional and financial models. When solarising for their energy needs, Indian farmers face high capital cost, low awareness about the technology and bureaucratic hurdles. Such issues impede the improvement of solar adoption rates in their fields. The earlier chapter discussed the slow growth in PM-KUSUM's Components C and A and the rationale behind it. Those rationales outline the Indian smallholders' challenges in adopting "solar as a third crop." In a country where over 85% of farmers are small and marginal, with a landholding size of less than 2 hectares (Agri-Census 2015-16), the role of institutions that can collectivize their efforts to ensure livelihood security is important.

Solar Cooperatives are an institutional model as shown in **Figure 5.1** that could help India accomplish its sustainable energy goals and enhance the farmers' livelihood outcomes. Solar cooperatives are community-based organizations formed by individuals, residential societies, businesses, and farmers. The objectives are to ensure that solar irrigation systems are collectively installed and managed, and the onus for maintaining those lies with the group members.

Advantages of Solar Cooperatives

Solar cooperatives in India's agriculture context are farmer collectives that own, manage, and maintain solar systems for their irrigation needs. In grid-connected systems, it augments income through energy sales to local power utility companies or institutions. Advantages of fostering farmer collectives in India's agricultural solarisation journey are discussed below:

- Solar cooperatives allow pooled resources of individual farmers to invest in larger

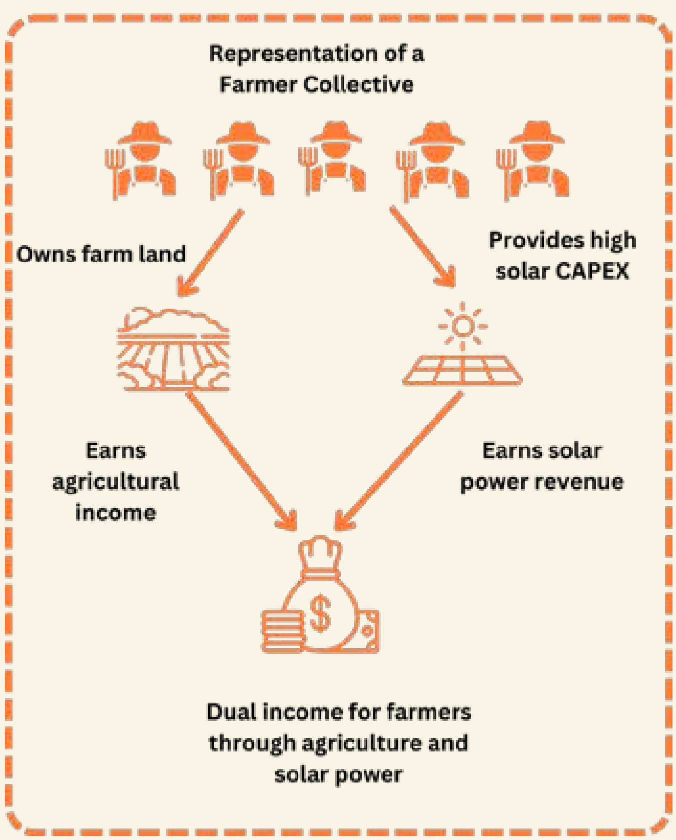
8. Source: Mordor Intelligence Report,2023, https://www.mordorintelligence.com/industry-reports/india-solar-energy-market

installed capacities of systems. With a collective, it is easier for individual farmers to invest in the high up-front cost needed to own solar irrigation systems.

- Solar Cooperatives enable farmers to negotiate better with vendors when purchasing bulk solar panels, equipment, and installation services. This lowers the overall installation cost, making them more affordable for the member farmers.
- Member farmers exchange insights and best practices, building their capacity to use and manage such systems successfully. When a community makes such an investment, and succeeds in enhancing its livelihood outcome, there is a knowledge spill over, and other farmer collectives are motivated to take up such initiatives.
- Solar-powered groundwater markets are gaining traction and are successful in places like Dhundi in Gujarat (Shah et al., 2017) and Chakhaji in Bihar (Durga et al., 2021). These markets provide affordable irrigation for tenant farmers and those without tube wells. Solar irrigation systems drastically reduce operating costs compared to diesel-based irrigation, making it a sustainable solution in states like West Bengal, Bihar, and Odisha, where diesel use in irrigation is prevalent (M, Kumari, Lad, & Maria, 2024). Solar cooperatives offer affordable irrigation to members and external buyers, creating an additional income stream for the cooperative while reducing irrigation costs of other farmers who are not members but are availing the services of the cooperative.

FIGURE 5.1

Schematic Diagram of a Solar Co-Operative



Source: Author's own.

Success Story of the World's First Solar Cooperative in Anand, Gujarat

In 2016, the Solar Pump Irrigators Cooperative Enterprise (SPICE) was established in Dhundi village of Anand, Gujarat, making it the world's first solar cooperative. The SPICE initiative launched by International Water Management Institute, Anand brought together nine small farmers (including two women farmers) who were reliant on diesel to meet their irrigation requirements and transformed them into solar pump users. A microgrid was set up that allowed these farmers to evacuate energy back to the grid providing them with an additional source of income by allowing them to "harvest the sun."

Each farmer contributed 10% of the pump's cost, with external agencies covering the remaining costs through grants. This ensured community ownership of the model. The cooperative installed solar panels with a combined capacity of 71.4 kWp that generated an income of roughly Rs. 20 lakhs through energy sales since installation. The model allowed farmers to sell the excess energy (after meeting their irrigation needs) to Madhya Gujarat Vij Company Ltd. (MGVCL) at Rs 4.63 per unit for 25 years (roughly the life cycle of solar irrigation systems). While farmers benefitted from reduced diesel costs, reliable day time solar power, and additional income from energy sales, MGVCL saved on grid power subsidies. The SPICE initiative demonstrates how solar cooperatives empowers small farmers by reducing diesel dependency and generating additional income through energy sales. Such farmer collective models offer a sustainable solution to farmers' energy and water challenges while promoting environmental and economic resilience.

Conclusion

Farmer collectives in India have experienced varying levels of success, with the dairy sector standing out as the most prominent and successful example. The success of dairy cooperatives, exemplified by India's "Operation Flood," showcases the potential of farmer collectives in transforming industries and empowering rural economies (Agarwal, 2010). Solar cooperatives could follow a similar trajectory by harnessing renewable energy to drive agricultural innovation if a supportive policy framework is guaranteed. Farmer collectives could be a viable business model for promoting APV in India. While there is limited research on the economic viability of such business models in promoting APV in the country, investment in APV through farmers' pooled resources could be a significant consideration for the future landscape of APV. The Sahyadri FPO is one of the few farmer collectives in India to invest in APV systems till now. Integrating solar energy with agricultural practices, such as grape and lemon cultivation, demonstrates the immense potential of APV to increase productivity and sustainability. It would be useful to know about the impact of shading on the productivity of such crops once the results of such initiatives are studied in depth and made public. Sahyadri Farms have come a long way from an annual turnover of 13 crore in 2012 to touching the milestone of Rs 1548 crores turnover in 2024 which allows them to invest in such technology[9]. However, FPOs like Sahyadri are rare in a landscape of over 8,500 registered FPOs, many of which struggle with low turnover and lack professional management and market grip to succeed (Bishnoi & Kumari, 2020). Most FPOs operate on limited resources, hence, making significant investments in infrastructure like APV systems (a 1 MW plant can cost ₹5-6 crore) is beyond their reach. To scale such innovative models, government intervention is essential. Policies that provide financial assistance, such as NABARD's Credit Guarantee Fund[10] or other similar initiatives, could enable FPOs to access the capital required for significant-scale investments. This fund covers 75% of the project costs up to INR 1.5 crore for projects exceeding INR 1 crore. With targeted support, cooperatives and FPOs could play a transformative role in combining renewable energy with sustainable agriculture, enhancing productivity, environmental benefits, and economic growth for India's farming communities.

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6

Harnessing the Sun

Case Studies of Agrivoltaics in India

Subhodeep Basu, Bidisha Banerjee, Laxmi Sharma and Soham Roy

Case Study 1: Agrivoltaic Innovation at Krishi Vigyan Kendra, Ujwa

Introduction

Krishi Vigyan Kendra (KVK) Ujwa is currently the only KVK in the country to install an APV at their site. The 110 kWp APV system at Ujwa was built with a CAPEX of 70000/ kWp and has been operational since February 2021. This experimental model is a benchmark for other KVKs in the country in conducting similar field experiments to unravel the potential of APV systems in the country for enhancing income augmentation opportunities for Indian farmers.

Project Overview

The APV system at KVK Ujwa spans 2000 sq. meters with 1500 sq. meters of overhead solar panels elevated at 3.5 meters to facilitate agricultural activities below the shade. The system features 335 Wp polycrystalline solar panels arranged in three rows with a 15-degree tilt. The system was installed by Oakridge Pvt. Ltd and the maintenance is done by the scientists at KVK Ujwa. A virtual net metering agreement has been made between NAFED, NHRDF, and KVK to govern the electricity generation and distribution of the plant. The generated energy is distributed at a ratio of 70:20:10 between the three parties respectively. KVK Ujwa is expected to pay Oakridge Ltd. for the energy generated at a FiT of Rs 3.14/unit of electricity. On an average, it has generated 1.4 lakh units of energy annually between 2021-2024.

FIGURE 6.1
110 kW APV at KVK, Ujwa

Source: Photo taken during field visit by APV team to Krishi Vigyan Kendra, Ujwa, Delhi.

Key features and Impact of the Intervention

Cropping Model: A three-tier farming approach is being implemented, consisting of ground-level farming and a shaded layer of cultivation under the solar panel. Solar energy is the third crop in such a model. Crops like tomato, brinjal, okra, and cauliflower are being cultivated. The same crops are grown outside the shading to observe the change in productivity. This is being done to compare the productivity of such crops under shaded infrastructure compared to open fields.

Income Benefits: The net return from cultivation under shade infrastructure and open fields stands at Rs 150000 and Rs 190000 per acre, respectively. Net returns from solar energy generation stand at Rs 360000 per acre annually. Combining the income from solar and crop production, the amount comes up to Rs 510000 per acre annually. Income from solar energy is roughly 70% of the total income, while the remaining 30% is from agriculture income. Compared to open cultivation, there is a 168% increase in income when solar is being harvested alongside crops.

Water Management Techniques

The panels are cleaned bi-weekly. For one time cleaning, a local 5000-liter water tanker costing Rs 1000-1500 is used to clean the panels. In addition, there is a rainwater harvesting structure with a capacity of 7.5 lakh litres. The rainwater harvesting ensures that the accumulated water is re-utilized for irrigation and panel cleaning purposes.

Key Takeaways

The model is agriculture centric considering 30% of total income from the plant is coming from agriculture. The substantial spacing of seven meters allows multiple crop cultivation under optimal sunlight conditions for photosynthesis. However, considering research pertaining to APV in the country is at a nascent stage, it is key to compare the productivity difference of crops under shaded infrastructure compared to open fields. Overall, on an average, there is a yield reduction of roughly 20% when crops are cultivated in APV set up compared to open field. For all the crops that are cultivated, a yield reduction has been observed. Crops like Hybrid cauliflower fortaleza and okra (Pusa Bhindi - 5) have recorded the lowest yield reduction while Brinjal (S-992) and Tomato (NS - 5013) have recorded the highest yield reduction. While there has been yield reduction of crops, the income enhancement through integration of solar and agriculture outweighs the income reduction through reduced yield.

KVK Ujwa's project showcases the potential of APV systems in generating clean energy, boosting farmer incomes, and promoting sustainable agriculture. By leveraging the expertise of institutions like KVKs, evidence-based scaling of APV across India could be considered. As a replicable blueprint for accelerating APV innovation in the country, the Ujwa initiative is a beacon for integrating renewable energy with agriculture in India for smallholders' economic empowerment.

Case Study 2: Agrivoltaic Innovation at Indian Council for Agricultural Research-Central Arid Zone Research Institute (ICAR-CAZRI), Jodhpur, Rajasthan

Introduction

The Central Arid Zone Research Institute (CAZRI) in Jodhpur hosts an innovative APV plant, blending sustainable energy production with agricultural innovation. This dual-use solar farming system optimizes land usage by integrating photovoltaic panels with crop cultivation. This plant addresses the region's challenges, such as water scarcity and high temperatures while promoting renewable energy application and enhancing agricultural productivity. By generating solar energy and providing partial shade for crops, the APV plant contributes to improved water efficiency, reduced soil degradation, and economic benefits for local farmers.

Project Overview

The ICAR-CAZRI APV project has an installed capacity of 105 kW and occupies an area of 1.14 acres. It was commissioned on 12th August 2017, and is a government owned plant. The project was developed at an approximate cost of ₹57,000 per kWp. Solar panels cover only 16% of the area, while the rest of the land is utilized for cultivation.

FIGURE 6.2

105 kW APV at ICAR-CAZRI, Jodhpur, Rajasthan

Source: Photo taken during field visit by APV team to ICAR-CAZRI, Jodhpur, Rajasthan.

Key features and Impact of the Intervention

System Design: The ICAR-CAZRI plant is an interspace APV system with Vikram Solar's monofacial polycrystalline panels of 260 Wp each, arranged in an East-West direction at a tilt angle of 26°. The setup is made of three blocks having a capacity of 35kW each and covering 1296 sqm (28mx28m) with respective heights of 1.22m, 1.94m and 2.66m above ground. A solar array is a system of multiple solar panels connected together to generate electricity from sunlight. The arrays in this plant are spaced as interspace width of 3m, 6m and 9m based on the block. The solar panels are fixed and do not include a tracking system. The overhead stilted design was done to simplify panel cleaning due to dust accumulation round the year. Instead measures like gaps between modules in some rows were introduced to support active photosynthesis for crops below. One array also acts as a natural shade net for climber crops such as bottle gourd that grow well in the shaded conditions. The plant features two 50 kW inverters, an automatic weather monitor for tracking wind speed and temperature, and includes albedo measurements conducted during setup to enhance efficiency.

Crops and Agricultural Aspect: The soil is sandy and loamy, supporting a variety of crops in three arrays: Array 1 for perennial crops, and Arrays 2 and 3 for *rabi* and *kharif* crops respectively. *Kharif* crops are mungbean, mothbean, and cluster bean; and *rabi* crops include isabgol, cumin, and chickpea. There are also medicinal plants such as aloe vera, sonamukhi, and sankhpuspi, and there are horticultural crops such as bottle gourd grown there. However, mild drought conditions often reduce the crop yield by 10-15%.

Energy Generation: The average energy generation from the system attached to the grid through a bi-directional energy meter or net meter is approximately 400 units per day. The feed-in-tariff is Rs.3.16/kW.

Economics: The plant has a payback period of 7 years, with a Levelized Cost of Electricity (LCOE) between ₹3.1-3.5/kWh. Electricity generated is sold at ₹3.16/kWh, producing 1,46,000 units annually and generating over ₹4.5 lakh in revenue each year.

Water Management Techniques: The panels are cleaned weekly, totalling four times a month. This system collects 60-80 thousand litres of rainwater every year using duct pipes fitted along the edges of the PV modules to facilitate irrigation and panel cleaning.

Key Takeaways

Power evacuation through India's grid remains a key challenge for scaling agrivoltaics (APV). Equally important is the need for farmer-centric models, as land is a critical asset for them. APV should be integrated into the PM-KUSUM scheme, but its scope must go beyond the current 500 kW to 2 MW capacity range. Smaller installations, up to 110 kW, should be promoted to prioritize agriculture, as larger MW-scale projects focus on energy generation and limit farmer participation due to high capital costs.

Additionally, the government must provide targeted financial assistance for APV projects, ensuring funds are used for advancing these initiatives. Expanding consultations and fostering active participation from Farmers' Producer Organizations (FPOs) is crucial for scaling APV effectively in the future.

Way Forward

Policy Recommendations Framework

Subhodeep Basu, Soham Roy, Laxmi Sharma and Bidisha Banerjee

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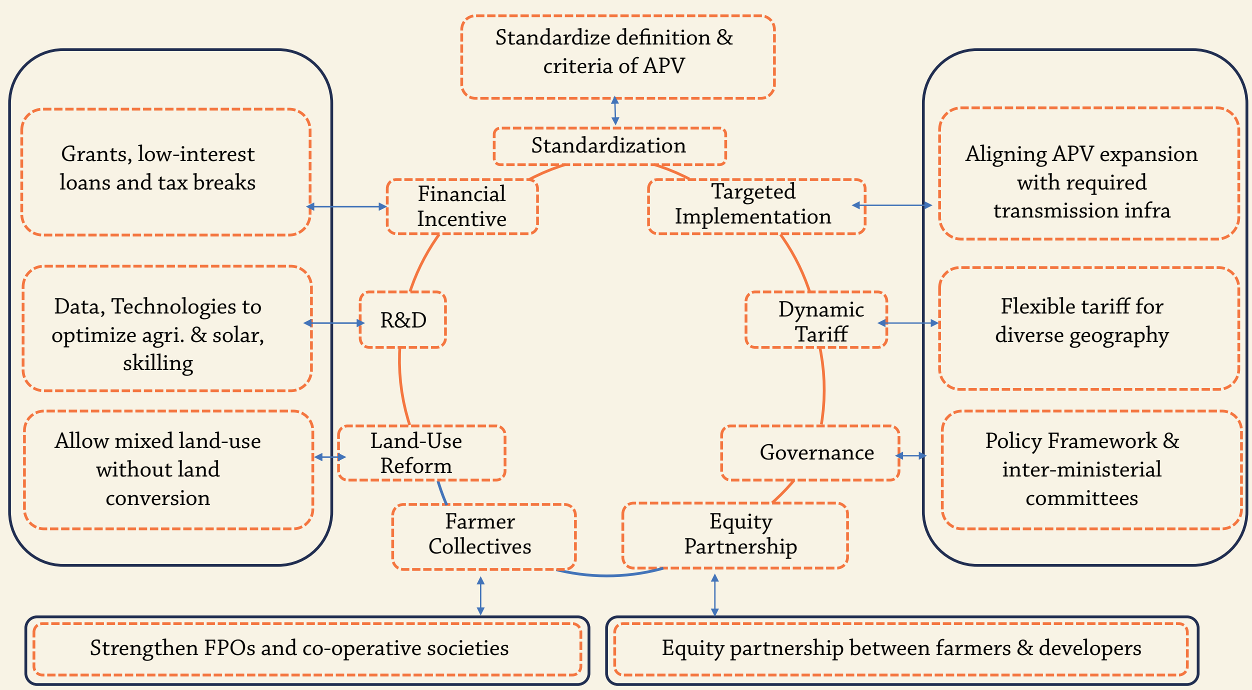
APV in India is in its early stages, so making a robust policy framework is essential for its adoption and scalability in the future. Developed through consultations with farmers, private players, and industry experts, the nine-point policy framework outlined in the next section and shown in **Figure 7.1** highlights the key areas needing focused attention and action from policymakers to drive APV growth in the country.

1. Standardization: The Key to Balancing Energy and Agriculture in APV Models

India can draw lessons from Germany and Japan, where clear conditions for APV are defined to balance energy generation with agricultural use. In Japan, converting farmland to temporary non-agricultural use requires approval from the local agricultural council. APV systems must meet strict criteria: mount-

FIGURE 7.1

Policy Recommendation Framework



Source: Author's Own.

ing structures should be temporary and easily removable, panel heights must be at least 2 meters to avoid disrupting agricultural activities, and crop yield reductions must not exceed 20% compared to average yields. Permits for APV operations must be renewed every three years, with continued approval dependent on satisfactory agricultural output under the APV system. Similarly, Germany has the DIN SPEC 91434 standard that defines APV as the agrarian yield after installation and must amount to 66% of the reference yield and land loss should not exceed 10-15%. Standardization ensures that the significance of agri in APV is not compromised if the returns from energy production become more remunerative. Clear guidelines defining what qualifies as APV are crucial for standardization. In the absence of standardisation, energy production, and management could get prioritized instead of enhancing agriculture productivity. Standardisation through setting uniform guidelines could be key in ensuring that agriculture remains the focus of APV initiatives across the country.

2. Boosting APV Adoption: Financial Incentives and Innovation for Scalable Solutions

To ensure that there is a wider adoption of APV systems in India, effective financial incentives must be rolled out. Financial incentives such as grants, low-interest loans, and tax breaks would help developers and agri-entrepreneurs to cover the high setup costs, making APV projects more viable. Supporting additional pilot projects that explore design configurations — such as variable orientations, tracking systems, and innovative structures — will encourage experimentation and reduce reliance on static, fixed-tilt systems. This will encourage the exploration of efficient and adaptive APV designs, driving more innovation and scalability.

3. Advancing Research & Development (R&D) and Specialized Training for Adaptive APV Systems

India needs a dedicated R&D program for designing APV systems optimized for the country's diverse climatic and geographical conditions. The present APV designs are not suited for regions that vary widely in temperature, humidity, and sunlight. Targeted R&D would help develop climate-resilient APV systems that maximize energy production while supporting sustainable agriculture. The results and data of such R&D programs should be available in the public domain. This will ensure knowledge spill over of such emerging technology to interested and potential stakeholders. This could be done through a database or portal where details of the APV plants in India are included.

Since this technology model is operating in its nascent stages in India, specialized training programs need to be developed for users. Training programs are effective for developing a skilled labour force capable of installing such systems and managing their maintenance. Installers need to be trained on integrating solar panels with agricultural production, such as ensuring proper crop shading while optimizing energy output. Finally, integrating smart technologies—like AI-driven automated solar panel cleaning systems could be prioritized. Such training and technologies enhance system performance and contribute to sustainable water use and farming practices.

4. Land-Use Policy Reforms for APV

States should create legal provisions for APV within their land-use and solar policies, allowing for mixed land use without converting land use status from agricultural land to non-agricultural land. This can be done by amending land-leasing laws (which are restrictive at present) in many states to facilitate APV projects. Adequate safeguards should be in place to prevent the misuse of these provisions. Policies on agricultural subsidies should be updated to clarify eligibility for projects, ensuring farmers access subsidies for precision irrigation and greenhouse technologies in APV systems.

5. Empowering Farmer Collectives for Sustainable Agrivoltaics Expansion

To accelerate the adoption of agrivoltaics (APV) in India, it is critical to strengthen farmer collectives, such as Farmer Producer Organizations (FPOs) and cooperatives, by enhancing their access to financial and technical resources. A targeted policy framework that facilitates access to capital, such as expanding NABARD's Credit Guarantee Fund and providing grants or subsidies for APV investments, can enable these institutions to overcome high upfront costs. Additionally, capacity-building programs must be rolled out to equip farmer collectives with the expertise required to manage and maintain APV systems.

6. Ensuring Agriculture Remains Central in Agrivoltaics Through Equity Partnership Models

To maintain a balance between agriculture and energy generation in agrivoltaics (APV), equity partnership models between farmers and private developers should be promoted, particularly in agriculturally productive regions. These models enable co-ownership, where farmers retain control over their land and collaborate with developers in co-designing APV systems. Farmers receive compensation for land use and can cultivate high-value crops suited to partial shading, while developers manage energy generation and sales. By allowing farmers to share in the equity and revenue, this approach ensures agriculture remains the focus of APV, avoiding the risk of energy generation overshadowing farming activities

7. Unified Governance and Policy Clarity: Driving APV Growth in India

To overcome regulatory uncertainties and support the growth of APV, the government should establish inter-ministerial committees involving the Ministries of Agriculture and MNRE. These bodies would provide coordinated governance, ensuring alignment between energy and agricultural policies. A dedicated APV policy framework should be developed for regulatory clarity and collaboration. As highlighted in earlier chapters, the current policy supporting solarization in agriculture is PM-KUSUM, extended until April 2026. Given the early development stage of APV in India, the timeline may need further extension, or PM-KUSUM should be restructured to better support the APV growth. PM-KUSUM 2.0 should be rolled out by including provisions for supporting APV on productive farmland. Enhanced governance structure, robust policy support, and a stronger institutional linkage between relevant ministries could be the key in driving the sector's success.

8. Dynamic Tariff Structures and Open-Access Promotion of APV need to be considered

To scale up APV, states must adopt a dynamic, location-sensitive feed-in tariff structure. For example, under the PM-KUSUM scheme, every state's SERC decides the feed-in tariff for the state. The FiT is determined through LCOE-based calculation that fails to consider the actual value of the land on which the plant is set up. For example, the FiT in an unproductive barren land of Rajasthan would be the same as in a peri-urban area where land productivity might be high. Owing to elevated panels and other design factors, the CAPEX of a typical APV plant is higher than that of a ground-mounted system. Thus, a uniform tariff is a disincentive for developers. Policymakers need to realize that FiT for a typical ground-mounted system cannot compete with the APVs.

Promoting APV through the open-access route could be considered as that would reduce the burden on DISCOMs to buy back energy. This would allow corporations and other large consumers to procure sustainable power directly from plants instead of DISCOMS while ensuring higher tariffs and better returns for APV developers. This strategy will boost APV adoption on economic and environmental merits.

9. Targeted Implementation of the APV in India: Aligning APV Expansion with Required Transmission Infrastructure

To optimize solar energy integration in rural areas, the government should issue facilitative guidelines for developing decentralized APV plants connected to 33/11 kV substations.

With around 40,000 such substations, connecting even 1 MW of solar power to each of these substations could add 40 GW capacity.

This would not only advance India's renewable energy goals but also significantly reduce T&D losses for discoms[8].

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Annexures

ANNEXURE A

Projected Total Installed Renewable Energy Capacity (TW) from 2019 to 2030: Current Trends vs. Target Achievement

Year	*Projected Total Installed Renewable Energy Capacity (TW)*	*Projected Total Installed Renewable Energy Capacity (TW) taking the target*
2019	1.1	1.1
2020	1.3	1.3
2021	1.5	1.5
2022	1.6	1.6
2023	2.0	2.0
2024	2.3	2.5
2025	2.6	3.2
2026	3.0	4.1
2027	3.4	5.3
2028	3.9	6.8
2029	4.5	8.7
2030	5.2	11.2
CAGR	14.87%	28.28%

Source: International Renewable Energy Agency (IRENA) and Author's Analysis.

ANNEXURE B

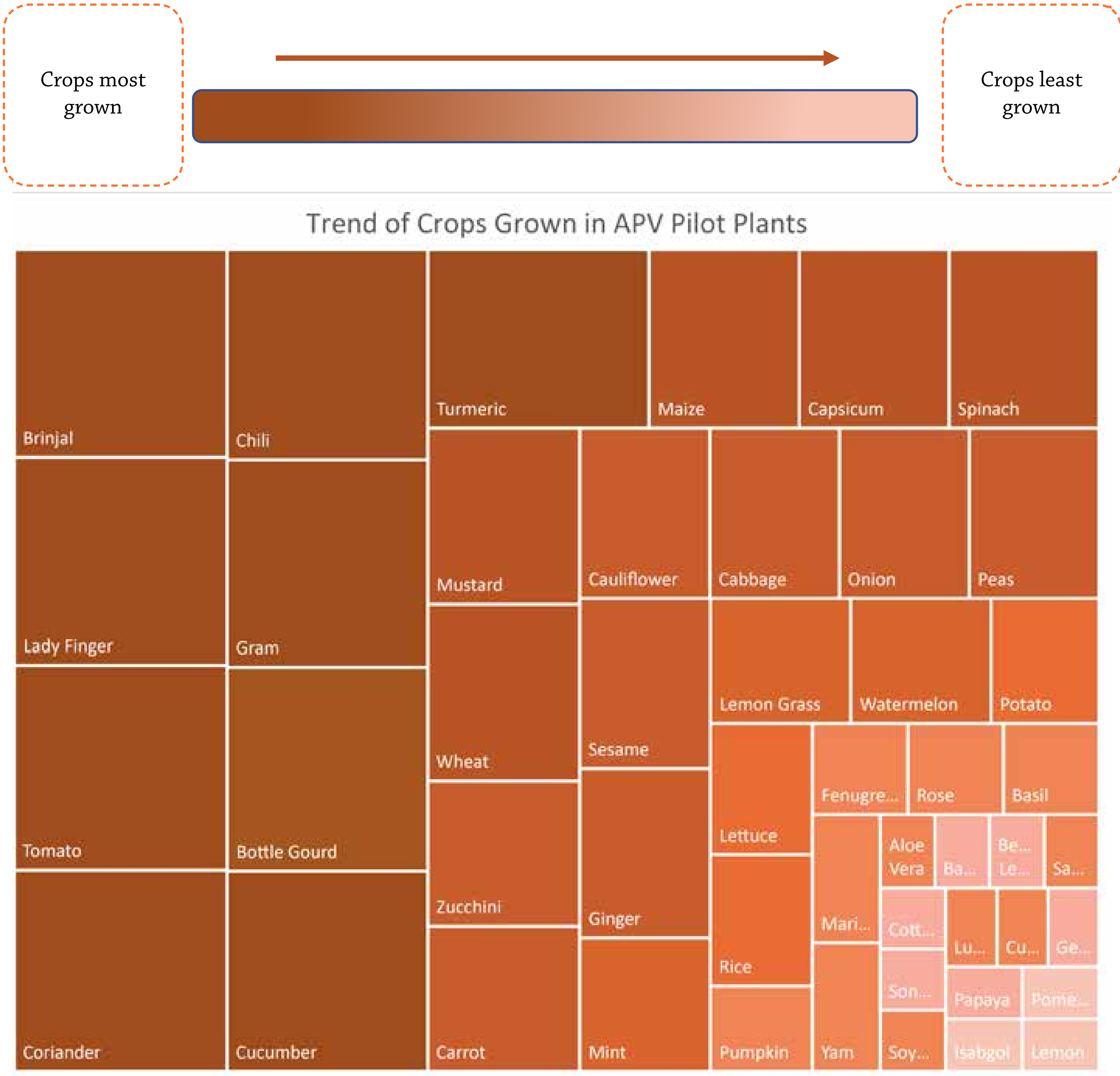
Popular Crops in APV Pilots in India

Table B1: List of Pilot APV Plants Considered to Study Popularity of Crops in India

S No.	*Name of APV Pilot Plant*	*State*	*Installed Capacity (in MW) (as of July 2023)*	*Ownership*
1.	GIPCL APV Plant	Gujarat	1	Government Supported/ Tendered as APV
2.	GSECL Harsha Abakus APV Plant (Sikka)	Gujarat	1	Government Supported/ Tendered as APV
3.	GSECL Harsha Abakus APV Plant (Pandhro)	Gujarat	1	Government Supported/ Tendered as APV
4.	CAZRI APV Plant	Rajasthan	0.1	R&D/Academic Plants
5.	Amity University APV Plant	Uttar Pradesh	0.01	R&D/Academic Plants
6.	Dayalbagh Agricultural University APV Plant	Uttar Pradesh	0.2	R&D/Academic Plants
7.	Junagadh Agriculture University APV Plant	Gujarat	0.007	R&D/Academic Plants
8.	Jain Irrigation APV Plant	Maharashtra	0.29	R&D/Academic Plants
9.	Krishi Vigyan Kendra (NHRDF) Ujwa APV Plant	Delhi	0.11	Government Supported/ Tendered as APV
10.	Parbhani APV Plant	Maharashtra	1.4	Commercial Pilots
11.	Hinren APV Rooftop (APVRT) System	Karnataka	0.003	Commercial Pilots
12.	Sunmaster APV System	Delhi	2	Commercial Pilots
13.	Abellon APV Plant	Gujarat	1	Commercial Pilots
14.	Mahindra Susten APV Plant	Telangana	0.4	Commercial Pilots
15.	Cochin Airport APV Plant	Kerala	4	Commercial Pilots
16.	NISE Vertical APV Plant	Haryana	0.005	R&D/Academic Plants
17.	Sandhwani APV Plant	Himachal Pradesh	0.25	Commercial Pilots
18.	Gro-Solar APV Plant	Maharashtra	1	Commercial Pilots
19.	Fish Pond APV Plant	Rajasthan	0.03	-
20.	Telangana University APV Plant	Telangana	0.01	R&D/Academic Plants
21.	Indra Solar Farm	Madhya Pradesh	0.4	Commercial Pilots

Source: Indo-German Energy Forum (IGEF) and National Solar Energy Federation of India (NSEFI).

Figure B2: Crops Grown in the Existing APV Plants in India



Source: Indo-German Energy Forum (IGEF) and National Solar Energy Federation of India (NSEFI) and Author's Analysis.

ANNEXURE C

Economic Feasibility of Agri-PV systems based on Author's own calculations

Table C1: Financial assumptions for a 2.5 MW APV Plant, based on stakeholder consultation.

Project Capacity	*MW*	*2.5*
Project Lifecycle	Years	27
Discount Rate	%	6%
(Project Capex -GST) at 3 m	INR/MW	₹ 4,00,00,000
GST	%	13.8
Capex at 3 m	INR/MW	₹ 4,55,20,000
Mounting Structure/Capex	%	10
Equity/Capex	%	30
Debt/Capex	%	70
Interest Rate	%	8.5
Loan Repayment Period	Years	7
O&M	INR/Year	₹ 20,00,000
Annual Escalation	%	1
Plant Insurance/Capex	%	0.1
Land Lease	INR/Acre/Year	₹ 1,00,000
Lease Escalation	%	3
Lease Escalation Interval	Years	5
Annual Generation	kWh/Mw	13,00,000
Total Annual Generation	kWh	32,50,000
Annual Tariff Escalation	%	3
Generation over Lifecycle	kWh	8,77,50,000

Table B2: Capex Breakdown for a 2.5 MW APV Plant

AGRI-PV PROJECT *2.5 MW*	*Structure Height 3 meter/9 feet*	*Structure Height 5 meter/15 feet*	*Structure Height 6 meter/18 feet*
Project CAPEX	₹ 11,38,00,000	₹ 12,13,86,667	₹ 12,51,80,000
Investment Share of Investor 30%	₹ 3,41,40,000	₹ 3,64,16,000	₹ 3,75,54,000
Investment Share of Bank 70%	₹ 7,96,60,000	₹ 8,49,70,667	₹ 8,76,26,000

Table C3: OPEX Breakdown for a 2.5 MW APV Plant over the lifecycle of 27 years

OPEX of 27 Years	*Structure Height 3 meter/9 feet*	*Structure Height 5 meter/15 feet*	*Structure Height 6 meter/18 feet*
Investor Loan Repayment in 7 Years 8.5% Interest Rate	₹ 12,70,57,700	₹ 13,55,28,213	₹ 13,97,63,470
Plant Insurance for 27 years @0.1% of Project CAPEX/Year	₹ 30,72,600	₹ 32,77,440	₹ 33,79,860
Plant O&M for 27 Years @1% Incremental Assumed	₹ 6,16,41,776	₹ 6,16,41,776	₹ 6,16,41,776
Labour Cost for 8 employees At 15000 Rs/Month	₹ 3,88,80,000	₹ 3,88,80,000	₹ 3,88,80,000
Lease/Rent to Farmer for 27 Years @5% Incremental as per Rent Control Act	₹ 1,29,88,902	₹ 1,29,88,902	₹ 1,29,88,902
TOTAL OPEX for 27 Years	₹ 24,36,40,978	₹ 25,23,16,331	₹ 25,66,54,008

Table C4: Revenue from sale of power with varying tariffs

FIT (Rs/ kWh)	*Revenue from Power Sale*	*Structure Height 3 meter/9 feet*	*Structure Height 5 meter/15 feet*	*Structure Height 6 meter/18 feet*
2.65	Total Sale to Discom (Rs)	₹ 35,06,11,719	₹ 35,06,11,719	₹ 35,06,11,719
	Investors Gross Profit After Sales (Without Tax and Depreciation)	₹ 9,10,82,741	₹ 8,01,31,387	₹ 7,46,55,711
3.25	Total Sale to Discom (Rs)	₹ 42,99,95,504	₹ 42,99,95,504	₹ 42,99,95,504
	Investors Gross Profit After Sales (Without Tax and Depreciation)	₹ 17,04,66,526	₹ 15,95,15,173	₹ 15,40,39,496
4.56	Total Sale to Discom (Rs)	₹ 60,33,16,769	₹ 60,33,16,769	₹ 60,33,16,769
	Investors Gross Profit After Sales (Without Tax and Depreciation)	₹ 34,37,87,791	₹ 33,28,36,438	₹ 32,73,60,761
5.1	Total Sale to Discom (Rs)	₹ 67,47,62,176	₹ 67,47,62,176	₹ 67,47,62,176
	Investors Gross Profit After Sales (Without Tax and Depreciation)	₹ 41,52,33,198	₹ 40,42,81,844	₹ 39,88,06,168
5.24	Total Sale to Discom (Rs)	₹ 69,32,85,059	₹ 69,32,85,059	₹ 69,32,85,059
	Investors Gross Profit After Sales (Without Tax and Depreciation)	₹ 43,37,56,081	₹ 42,28,04,728	₹ 41,73,29,051
5.47	Total Sale to Discom (Rs)	₹ 72,37,15,510	₹ 72,37,15,510	₹ 72,37,15,510
	Investors Gross Profit After Sales (Without Tax and Depreciation)	₹ 46,41,86,532	₹ 45,32,35,179	₹ 44,77,59,502

Table C5: Cash Inflow from agriculture over 27 years

Agricultural Revenue of 27 Years	*Structure Height 3 meter/9 feet*	*Structure Height 5 meter/15 feet*	*Structure Height 6 meter/18 feet*
Assuming Turmeric and Potato At constant prices, yield and cost of production	₹ 1,82,52,000	₹ 1,82,52,000	₹ 1,82,52,000

Table C6: Cash Outflow over 27 years for a 2.5 MW APV Plant with Tariff 5.1 Rs/kWh

Year	*Equity (Rs)*	*O&M(Rs)*	*Loan Repayment (Rs)*	*Plant Insurance (Rs)*	*Land Rent (Rs)*	*Labour (Rs)*	*Total (Rs)*
0	3,41,40,000	20,00,000	1,81,51,100	1,13,800	4,50,000	14,40,000	5,62,94,900
1	0	20,20,000	1,81,51,100	1,13,800	4,50,000	14,40,000	2,21,74,900
2	0	20,40,200	1,81,51,100	1,13,800	4,50,000	14,40,000	2,21,95,100
3	0	20,60,602	1,81,51,100	1,13,800	4,50,000	14,40,000	2,22,15,502
4	0	20,81,208	1,81,51,100	1,13,800	4,50,000	14,40,000	2,22,36,108
5	0	21,02,020	1,81,51,100	1,13,800	4,63,500	14,40,000	2,22,70,420
6	0	21,23,040	1,81,51,100	1,13,800	4,63,500	14,40,000	2,22,91,440
7	0	21,44,271	0	1,13,800	4,63,500	14,40,000	41,61,571
8	0	21,65,713	0	1,13,800	4,63,500	14,40,000	41,83,013
9	0	21,87,371	0	1,13,800	4,63,500	14,40,000	42,04,671
10	0	22,09,244	0	1,13,800	4,77,405	14,40,000	42,40,449
11	0	22,31,337	0	1,13,800	4,77,405	14,40,000	42,62,542
12	0	22,53,650	0	1,13,800	4,77,405	14,40,000	42,84,855
13	0	22,76,187	0	1,13,800	4,77,405	14,40,000	43,07,392
14	0	22,98,948	0	1,13,800	4,77,405	14,40,000	43,30,153
15	0	23,21,938	0	1,13,800	4,91,727	14,40,000	43,67,465
16	0	23,45,157	0	1,13,800	4,91,727	14,40,000	43,90,684
17	0	23,68,609	0	1,13,800	4,91,727	14,40,000	44,14,136
18	0	23,92,295	0	1,13,800	4,91,727	14,40,000	44,37,822
19	0	24,16,218	0	1,13,800	4,91,727	14,40,000	44,61,745
20	0	24,40,380	0	1,13,800	5,06,479	14,40,000	45,00,659
21	0	24,64,784	0	1,13,800	5,06,479	14,40,000	45,25,063
22	0	24,89,432	0	1,13,800	5,06,479	14,40,000	45,49,711
23	0	25,14,326	0	1,13,800	5,06,479	14,40,000	45,74,605
24	0	25,39,469	0	1,13,800	5,06,479	14,40,000	45,99,748
25	0	25,64,864	0	1,13,800	5,21,673	14,40,000	46,40,337
26	0	25,90,513	0	1,13,800	5,21,673	14,40,000	46,65,986
Total	3,41,40,000	6,16,41,776	12,70,57,700	30,72,600	1,29,88,902	3,88,80,000	27,77,80,978

Table C7: Cash Inflow over 27 years for a 2.5 MW APV Plant with Tariff 5.1 Rs/kWh

Cash Inflow			
Year	*Revenue - Power*	*Revenue - Agriculture*	*Total*
0	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
1	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
2	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
3	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
4	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
5	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
6	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
7	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
8	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
9	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
10	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
11	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
12	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
13	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
14	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
15	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
16	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
17	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
18	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
19	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
20	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
21	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
22	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
23	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
24	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
25	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
26	₹ 2,49,91,192	₹ 6,76,000	₹ 2,56,67,192
Total	₹ 67,47,62,176	₹ 1,82,52,000	₹ 69,30,14,176

Table C8: Economic feasibility indicators over 27 years for a 2.5 MW APV Plant with Tariff 5.1 Rs/kWh

NPV	*INR*	*₹ 14,96,38,260*
IRR	%	26%
Payback Period	Years	8
Discounted Payback Period	Years	8

Table C9: Economic feasibility indicators over 27 years for a 2.5 MW APV Plant at 3 m height with varying tariffs

Height		*3 m*					
Agriculture Practised		*No*			*Yes*		
FIT (Description)	*FIT (INR/ Unit)*	*NPV (INR)*	*IRR (%)*	*Payback Period (Years)*	*NPV (INR)*	*IRR (%)*	*Payback Period (Years)*
FIT as per Current Ground Mounted APPC (Assumed)	2.65	-₹ 1,78,92,086	4%	19	-₹ 89,61,765	5%	18
PM Kusum Component A	3.25	₹ 2,09,48,736	8%	14	₹ 2,98,79,057	9%	13
FIT as per Current APPC of Thermal Power	4.56	₹ 10,57,51,199	19%	9	₹ 11,46,81,520	20%	9
FIT as per Actual APPC as per Current PPA	5.1	₹ 14,07,07,939	24%	8	₹ 14,96,38,260	26%	8
FIT as per 15% Premium on Thermal Power	5.24	₹ 14,97,70,797	26%	8	₹ 15,87,01,119	28%	8
FIT as per 20% Premium of Thermal Power	5.47	₹ 16,46,59,779	29%	8	₹ 17,35,90,101	31%	7

Table C10: Economic feasibility indicators over 27 years for a 2.5 MW APV Plant at 5 m height with varying tariffs

Height		*5m*					
Agriculture Practised		*No*			*Yes*		
FIT (Description)	*FIT (INR/ Unit)*	*NPV (INR)*	*IRR (%)*	*Payback Period (Years)*	*NPV (INR)*	*IRR (%)*	*Payback Period (Years)*
FIT as per Current Ground Mounted APPC (Assumed)	2.65	-₹ 2,68,94,571	3%	20	₹ -1,79,64,250	4%	19
PM Kusum Component A	3.25	₹ 1,19,46,252	7%	15	₹ 2,08,76,573	8%	14
FIT as per Current APPC of Thermal Power	4.56	₹ 9,67,48,714	17%	10	₹ 10,56,79,035	18%	10
FIT as per Actual APPC as per Current PPA	5.1	₹ 13,17,05,454	21%	9	₹ 14,06,35,775	23%	8
FIT as per 15% Premium on Thermal Power	5.24	₹ 14,07,68,313	23%	8	₹ 14,96,98,634	24%	8
FIT as per 20% Premium of Thermal Power	5.47	₹ 15,56,57,295	25%	8	₹ 16,45,87,616	27%	8

Table C11: Economic feasibility indicators over 27 years for a 2.5 MW APV Plant at 6 m height with varying tariffs

Height		*6m*					
Agriculture Practised		*No*			*Yes*		
FIT (Description)	*FIT INR/ Unit)*	*NPV (INR)*	*IRR (%)*	*Payback Period (Years)*	*NPV (INR)*	*IRR (%)*	*Payback Period (Years)*
FIT as per Current Ground Mounted APPC (Assumed)	2.65	-₹ 3,13,95,813	3%	21	-₹ 2,24,65,492	4%	19
PM Kusum Component A	3.25	₹ 74,45,009	7%	16	₹ 1,63,75,330	8%	15
FIT as per Current APPC of Thermal Power	4.56	₹ 9,22,47,472	16%	10	₹ 10,11,77,793	17%	10
FIT as per Actual APPC as per Current PPA	5.1	₹ 12,72,04,212	20%	9	₹ 13,61,34,533	21%	9
FIT as per 15% Premium on Thermal Power	5.24	₹ 13,62,67,071	21%	9	₹ 14,51,97,392	23%	8
FIT as per 20% Premium of Thermal Power	5.47	₹ 15,11,56,052	24%	8	₹ 16,00,86,374	25%	8

Figure C1: IRR of APV system at 6 m mounting height

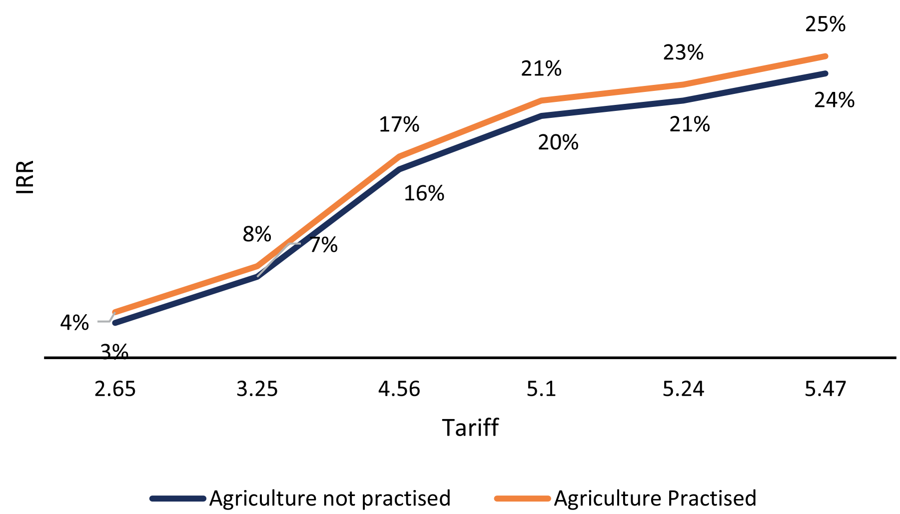
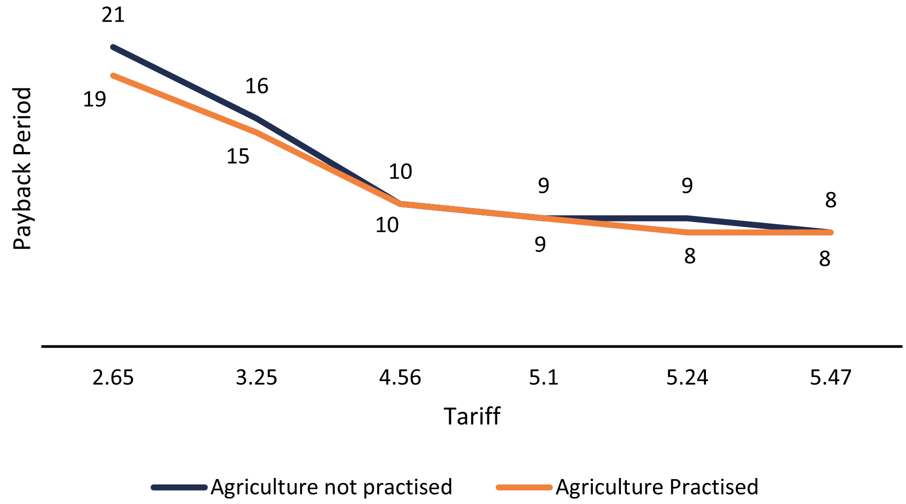


Figure C2: Payback Period of APV system at 6 m mounting height



ANNEXURE D

Photos from the Field

Annexure D1: Sunmaster APV Plant, Najafgarh, Delhi on 2nd September 2024

Annexure D2: Krishi Vigyan Kendra APV Plant, Ujwa, Delhi on 12th November 2024

Annexure D3: Indian Council of Agricultural Research- Central Arid Zone Research Institute (ICAR-CAZRI) on 25th November 2024