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Tariff Design and Revenue Optimization for Agrivoltaics Projects under the PM-KUSUM Scheme: A Financial Viability Analysis for Madhya Pradesh, India#

Suhas Sathyakiran[1*], Sheikh Madiha Syed[2], Sarita Vijayvargiya[3], Saptak Ghosh[4]

Center for Study of Science, Technology, and Policy (CSTEP), Bengaluru, Karnataka, 560094, India

(Corresponding Author: suhas.sathyakiran@cstep.in)

ABSTRACT

Agrivoltaics co-locates solar photovoltaic power generation with agricultural crop cultivation on the same land, optimizing land use and providing dual income streams for farmers. This paper investigates tariff design and revenue optimization for agrivoltaic systems under the Indian PM-KUSUM scheme, for the state of Madhya Pradesh. Using a financial comparison framework, the study analyzes different business models: farmer-owned with and without Agriculture Infra Fund (AIF) loans, and developer-owned with leased land. Despite 20% higher capital costs due to elevated solar structures, agrivoltaics generate additional revenue from crop production, exemplified by Aloe Vera cultivation, which significantly improves financial returns. The analysis indicates that an increase of USD 0.0082 to 0.011 per kWh above current tariffs is required for project viability, highlighting the need for differentiated tariff mechanisms. Sensitivity analysis across tariff rates ranging from USD 0.03 to 0.049 per kWh highlights that tariff differentiation enhances internal rate of return (IRR), return on equity (ROE), cumulative revenue, and shortens payback periods, making the technology financially viable. High-income crop selection such as Aloe Vera can dramatically improve cash flows and investment attractiveness by boosting agrivoltaics' revenue potential. These results underscore the necessity for policy frameworks that incorporate tariff mechanisms recognizing the unique cost and revenue characteristics of agrivoltaics, thus enabling scalable adoption of sustainable energy in agriculture. This study provides actionable insights for policymakers and stakeholders to optimize tariff structures and revenue models to support India's renewable energy transition and agrarian growth.

Keywords: Agrivoltaics, tariff design, revenue optimization, PM-KUSUM scheme, return on equity, payback period

1. INTRODUCTION

India faces the twin challenge of meeting growing energy demand while ensuring food security and sustainable agricultural livelihoods. Agrivoltaics (AgriPV), the co-location of solar photovoltaic (PV) power generation with crop cultivation on the same land represents a promising innovation that optimizes land use efficiency. By combining solar energy production with farming, agrivoltaics can simultaneously boost renewable energy capacity and augment farmer incomes without compromising food production.

The Government of India's PM-KUSUM scheme promotes solarization of agricultural pumps and decentralized solar generation to support energy access and agricultural productivity. While conventional ground-mount solar projects have lower capital costs, agrivoltaics enable additional revenue through crop cultivation under solar panels, improved microclimates that can boost water use efficiency and crop yields, and reduced land use conflict. The 20% - 30% higher installation cost for agrivoltaics reflects elevated mounting structures and site engineering requirements.

Early pilot projects across various agro-climatic zones have demonstrated agrivoltaics' potential to enhance land productivity, generate supplementary income, and contribute to rural electrification and climate change mitigation. Additionally, selecting high-value crops such as Aloe Vera significantly improves financial returns, making the business model compelling for farmers and developers.

However, tariff structures under PM-KUSUM currently do not fully recognize agrivoltaics' unique cost-revenue profile. This study presents a detailed financial comparison of agrivoltaics versus ground-mounted solar systems, incorporating sensitivity analyses on tariff rates and crop revenue optimization. The objective is to inform tariff design mechanisms and investment decision-

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making to scale agrivoltaics for India's sustainable energy and agricultural future.

2. METHODOLOGY AND SCIENTIFIC INNOVATION

a. Methodology

This study employs a comprehensive financial and techno-economic analysis framework tailored to agrivoltaics under the PM-KUSUM program for Madhya Pradesh, India. The methodology integrates multiple stakeholder business models, tariff sensitivity scenarios, and crop revenue optimizations using detailed assumptions and data gathered from primary sources, literature, and field consultations.

Financial Comparison Framework -

Three principal business models were analyzed:

- Farmer-owned model with Agriculture Infrastructure Fund (AIF) loans: where farmers leverage government-subsidized loans under AIF scheme to finance agrivoltaic installations on their land.
- Farmer-owned model with PM-KUSUM loans: where farmers leverage loans given under PM-KUSUM scheme to finance agrivoltaics installation on their land.
- Developer-owned model using leased land: where third-party developers own and operate agrivoltaic installations on leased farmland with USD 490.82 as the lease rent escalating annually at 5%.

Each model's financial metrics were computed, including installation costs, cumulative net revenues, payback period, internal rate of return (IRR), and return on equity (ROE).

Data Sources and Assumptions -

- Installation costs include elevated structural systems for agrivoltaics, which account for a 20% cost premium over ground-mount solar due to additional materials and engineering requirements.
- Crop revenue considered average annual net income per acre for typical agricultural produce which is USD 545.36, assumed to escalate at a 7.3% annual growth rate based on National Bank for Agriculture and Rural Development (NABARD) agricultural revenue data.
- Sensitivity analysis was conducted on tariff rates to evaluate their impact on IRR, ROE, payback periods, and cumulative revenues in each business model. Tariff rates examined ranged from USD 0.03 to USD 0.049 per kWh under PM-KUSUM tariff structures, including increments necessary to ensure financial feasibility (14% ROE for the project according to Central Electricity Regulatory Commission (CERC)) for agrivoltaics.
- A high-value crop scenario was modeled with Aloe Vera cultivation, incorporating its specific average net revenue which is USD 6,446 per annum and cost profiles to assess impact on overall financial viability.
- Debt to equity ratios, loan tenors, interest rates, Operation and Maintenance (O&M) costs, and loan amortization schedules were set consistent with typical renewable energy financing parameters in India and they are listed in Table - 1.

Parameters	Value	Units
Area required for 1 MW agrivoltaics system	4.5	acres
Agrivoltaics Installed Capacity	1000	kW
Installation costs of a 1 MW agrivoltaics system	436,288	USD
Debt to equity ratio	0.7	%
Capacity Utilization Factor (CUF)	21	%
Current Feed in tariff of	0.035	USD per kWh

KUSUM-A in MP		
Bank interest rate under AIF loans	4	%
Bank interest rate under PM-KUSUM loan	7	%
Max Loan tenure under AIF	7	Years
Loan tenure for loans under PM-KUSUM	10	Years
Installation cost for 1 MW of Ground mount Plant under KUSUM - A	354,484	USD
Delta difference between Agrivoltaics and Ground Mount plant	81,804	USD
Accelerated Depreciation for Solar Projects in India	40	%
Tax Rate	30%	%

Table 1 Assumptions used for the techno-economic analysis

b. Methodological Innovation

- This study is among the first to formally integrate crop revenue in financial modeling for agrivoltaics within the PM-KUSUM policy framework, quantifying how crop choice especially high-value crops like Aloe Vera can shift economic outcomes.
- The analysis explicitly evaluates tariff deltas needed for agrivoltaic viability compared to ground-mounted solar, providing actionable tariff design insights for policymakers.
- It assesses multiple stakeholder business models with varying ownership, financing, and land-use arrangements to capture the heterogeneous investment landscape in Indian agriculture.
- Financial projections use dynamic escalation rates rather than static values, better modeling real-world income progressions and costs.

3. RESULTS

The financial assessment comparing agrivoltaics with conventional ground-mount solar under the PM-KUSUM scheme reveals distinct economic trade-offs across business models. Agrivoltaics require approximately 20% higher capital expenditure due to elevated mounting structures enabling crop cultivation beneath panels. Despite this, cumulative net revenues were consistently higher in agrivoltaics across farmer-owned and developer-owned models, driven by additional income from crop production but the return on equity and IRR for agrivoltaics was lesser than ground mount system at current feed-in-tariff of USD 0.035 per kWh as discussed in Table 2, Table 3 and Table 4.

Parameters	Ground Mount	Agrivoltaics
Cumulative Net Revenue	USD 405,748	USD 423,199
Payback Period	9 Years	11 Years
IRR	12%	9%
ROE	13%	11%

Table 2 Financial Comparison of Ground Mount Systems with Agrivoltaics for Farmer owned with AIF loans

Parameters	Ground Mount	Agrivoltaics
Cumulative Net Revenue	USD 413,383	USD 431,925
Payback Period	10 Years	12 Years
IRR	11%	9%
ROE	13%	11%

Table 3 Financial Comparison of Ground Mount Systems with Agrivoltaics for Farmer owned with PM-KUSUM loans

Parameters	Ground Mount	Agrivoltaics
Cumulative Net Revenue	USD 353,393	USD 354,484
Payback Period	10 Years	13 Years
IRR	10%	8%
ROE	11%	9%

Table 4 Financial Comparison of Ground Mount Systems with Agrivoltaics for developer owned model

Sensitivity analysis on tariff rates from USD 0.03 to 0.049 per kWh underscores that an increment of USD 0.008 to 0.011 per kWh above existing tariffs is critical for making agrivoltaics financially viable. Under current tariff structures (USD 0.035 per kWh), the internal rate of return (IRR) ranges between 8-9% for agrivoltaics, which improves to 14-15% at tariffs of USD 0.049, reducing payback periods from over 11 years to around 8 years in all the models as shown in Table 5, Table 6 and Table 7.

KUSUM - A Feed-in-Tariff for APV (USD/kWh)	IRR (%)	ROE (%)	Payback Period (Years)
0.030	6	7	16
0.033	8	9	12
0.035	9	11	11
0.038	**10**	**14**	**10**
0.041	**11**	**15**	**9**
0.044	13	17	9
0.046	14	20	8
0.049	15	22	8

Table 5 Sensitivity Analysis of Feed-in-Tariff for Farmer owned model with AIF loans

KUSUM - A Feed-in-Tariff for APV (USD/kWh)	IRR (%)	ROE (%)	Payback Period (Years)
0.030	6	7	17
0.033	7	9	15
0.035	9	11	12
0.038	**10**	**14**	**11**
0.041	**11**	**16**	**10**
0.044	12	18	9
0.046	14	20	8
0.049	15	22	8

Table 6 Sensitivity Analysis of Feed-in-Tariff for Farmer owned model with PM-KUSUM loans

KUSUM - A Feed-in-Tariff for APV (USD/kWh)	IRR (%)	ROE (%)	Payback Period (Years)
0.030	5	5	18
0.033	6	7	16
0.035	8	9	13
0.038	9	11	11
0.041	**10**	**14**	**10**
0.044	**12**	**16**	**10**
0.046	13	18	9
0.049	14	20	8

Table 7 Sensitivity Analysis of Feed-in-Tariff for developer owned model

Crop-specific revenue optimization significantly enhances financial returns. For instance, Aloe Vera cultivation, a high-value and shade-tolerant crop, substantially elevated cumulative net revenues and investment metrics. ROE improved by 7-8% and payback periods shortened by 3-5 years depending on ownership and loan models, highlighting crop selection's transformative effect on agrivoltaics' economic viability as shown in Table 8, Table 9 and Table 10.

Parameters	Agrivoltaics considering average annual crop revenue of India	Agrivoltaics considering Aloe Vera crop cultivation
Cumulative Net Revenue	USD 476,644	USD 1,040,547
Payback Period	11 Years	9 Years
IRR	10%	19%
ROE	12%	27%

Table 8 Financial Comparison of Agrivoltaics with average crop net revenue and Aloe vera for farmer owned model with AIF loans

Parameters	Agrivoltaics considering average annual crop revenue of India	Agrivoltaics considering Aloe Vera crop cultivation
Cumulative Net Revenue	USD 431,925	USD 942,382
Payback Period	12 Years	9 Years
IRR	9%	15%
ROE	11%	26%

Table 9 Financial Comparison of Agrivoltaics with average crop net revenue and Aloe vera for farmer owned model with PM-KUSUM loans

Parameters	Agrivoltaics considering average annual crop revenue of India	Agrivoltaics considering Aloe Vera crop cultivation
Cumulative Net Revenue	USD 354,484	USD 918,386
Payback Period	13 Years	10 Years
IRR	8%	14%
ROE	9%	24%

Table 9 Financial Comparison of Agrivoltaics with average crop net revenue and Aloe vera for Developer led model

4. CONCLUSIONS

These findings highlight key implications for tariff design and policy. Current PM-KUSUM tariff frameworks require adjustment to reflect the distinct capital intensities and dual revenue streams of agrivoltaics. Tariff enhancements aligned with agrivoltaic system costs and revenues can catalyze adoption, incentivize developers, and optimize farmer incomes. Additionally, promoting high-value crop cultivation under agrivoltaic structures can mitigate risks and improve project bankability. The key insights gained from the study is illustrated in Fig. 1.

Operational challenges such as higher structure fabrication costs and maintenance accessibility were noted but are considered addressable through technological innovation and scale economies. The synergistic benefits of agrivoltaics, including improved microclimates for crops, water use efficiency, and diversified income sources, position the concept as a promising enabler for sustainable energy-agriculture integration in India's context.

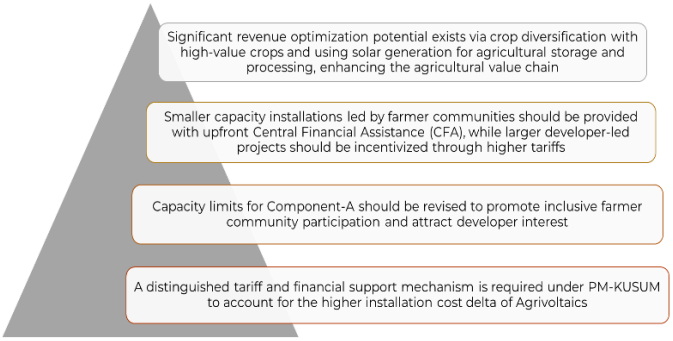

Fig. 1 Key insights gained from the study

Overall, the integration of tariff sensitivity, multi-model financial analysis, and crop revenue optimization presents a robust framework informing policymakers, investors, and farming communities about pathways for successful agrivoltaic scaling under PM-KUSUM.

5. ACKNOWLEDGEMENTS, FEATURES AND MEDIA HIGHLIGHTS

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