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Financial viability assessment of agrophotovoltaic systems in India

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ABSTRACT

The feasibility of Agrophotovoltaics (APV) has been studied by several researchers in terms of, design considerations, and implementation with different crops. However, the economic feasibility of the installation of elevated solar photovoltaic panels in diverse crops in India needs to be assessed for wider adoption. Hence, in the current study, the financial implication of APV by growers/farmers through cash flow analysis, and calculation of financial indicators like Internal Rate of Return (IRR), Debt Service Coverage Ratio (DSCR), and Net Present Value (NPV) were assessed. The input data for the analysis was collected during 2024 using the past two years' average numbers for India from the Economic Survey published by the Ministry of Finance, Government of India. Findings inferred that the financial performance of APV projects is dependent on several variables such as the effect on the yield, coverage of solar panels, feed-in tariff, cost of debt, etc. Therefore, sensitivity analysis with these variables has been conducted to highlight the areas where intervention will be most effective in facilitating large-scale implementation in India. The results demonstrate that the concept is financially viable and can potentially help in the income diversification of various segments of the farmers. However, the major challenge may be the high upfront equity investment, and also financial performance is highly sensitive to the price of power that is exported to the grid.

Key words: Financial analysis, Internal Rate of Return, Payback Period, Solar photovoltaics

The term Agrophotovoltaics is a combination of two words i.e. agro and photovoltaics. When solar photovoltaic panels are installed over agricultural fields, it is referred to as Agrophotovoltaics (APV). The APV concept was developed by Adolf Goetzberger and Armin Zastrow back in 1981(Goetzberger and Zastrow 1982). The concept is known by different names such as agrivoltaics, agro photovoltaics in Germany, agrovoltaics in Italy, and solar sharing in Asia. Researchers have also called them Aglectric systems (Grubbs *et al.,* 2020).

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agroecosystems (Santra *et al.,* 2018; Patel *et al.,* 2019). However, the financial viability of APV needs to be established from a farmer's perspective in the Indian context. Hence, the current study was undertaken to assess the economic feasibility of different APVs under diverse Indian agroecosystems.

MATERIALS AND METHODS

The financial viability of the APV system has been studied through the cash flow analysis over 15 years and calculation of some of the commonly used financial indicators.

***Net Present Value*: **It is an economic indicator for a project and its value does not change even if the financial resourcing changes (Tang and Tang, 2003). The cash outflows are subtracted from the project's cash inflows. The formulae used for the calculation are:

$$NPV = \sum_{y=1}^{N} \frac{CI_y - CO_y}{(1+r)^y}$$

Where CI_y is the cash inflow in the year t; CO_y is the cash outflow in the year y; N is the project life and r is the discount rate in percent. It provides a societal view of the investment and depicts the economic value it creates for society. A positive NPV represents a net value creation by the project or investment.

Internal Rate of Return: It represents the average annual rate of return with a condition that extra cash from the project is reinvested into the project at a rate that is equal to IRR (Miletic and Latinac 2020). It is a financial indicator from an investor's point of view (Tang and Tang 2003) and it varies with the financial resourcing. It is the rate of return at which the NPV becomes zero. For a project to be financially viable, the IRR should be more than the cost of the project's capital, (Miletic and Latinac 2020).

***Average Debt Service Coverage Ratio (Av*DSCR):** It is a financial indicator that indicates the ability of a borrower/project to fulfil its debt obligations (Dasinis and Annette 2022). The average DCSR is calculated by averaging the annual DSCRs over the period of the project.

$$AvDSCR = \frac{\sum_{y=1}^{N} {NC_y}/{EMI_y}}{N}$$

Where, NC_y is the net cash inflow for year y, EMI_y is the equated monthly instalment for the debt in the year y, and N is project period. Theoretically, DSCR of more than one with some safety buffer is required by the lender, the higher the value better the project performance.

Payback Period: This is the period in which the investor can recover its investment through the project cash flow. Further sensitivity analysis was conducted to determine the impact on financial indicators with changes in some of the key assumptions and input values. The objective of the sensitivity analysis is to identify the parameters to which the financial viability of the project is most sensitive and where the intervention will be most effective.

Assumptions

The assumptions or input values (Table 1) for the financial analysis have been taken from secondary sources that are widely accepted and representative of the Indian context.

The data for assumptions was gathered in 2024 using the past two years average numbers for India from Economic Survey published by Ministry of Finance, India.

RESULTS AND DISCUSSION

Base Case

The financial analysis of a typical agro photovoltaic project on a land parcel of 1 ha was conducted through the cash flow analysis for 15 years and input values mentioned in the assumptions section (Table1) above were used to calculate the financial indicators for the performance of the project. A shading of 25% has been assumed for the analysis, as it has been identified as the optimum shading ratio from 2021 to 2050 (Kim and Kim, 2023). In the base case, the net present value of the cash flow is ₹1,124,262 which is positive, the Internal Rate of Return for the project has been calculated as 15.55%, the average Debt Service Coverage Ratio is 1.53, and the payback period is 6 years. This shows that the project is financially viable for the farmer providing good returns on the investment with a payback period of 6 years and providing sufficient cash flow for the repayment of the debt.

The annual cash inflow for the farmer increases manifolds, diversifying their source of income and reducing their vulnerability to the changing weather patterns, floods, droughts, and other impacts of climate change. The performance of APV systems may increase with the use of bifacial and semi-transparent panels (Valle *et al.,* 2017). Further, the assumed reduction in the agricultural yield of the crops does not have a substantial impact on the income of the farmer for two reasons. Firstly, the reduction in the crop yield is only about 8% which may be even lower in the case of a tropical country like India. On the contrary, the installation of PV panels on the crops providing some shading can increase the yield by protecting the crop from harsh sun and heat waves. It has been observed while assessing the economic feasibility of *Bupleurum chinense* and *Medicago sativa* in China under PV panels (Zhang *et al.,* 2024), that the APV system may increase the yield of crops by about 30%. Also, the impact on the yield per ha cannot be determined with certainty (Ketzer *et al.,* 2020), as it is highly dependent on the crop type and weather conditions. The impact of the panel

Table 1. Assumptions for the financial analysis

S.No.	Parameter	Value	Source
1.	Farm area available	1 ha	Assumed
2.	Percentage of land covered with solar photovoltaic panels	25%	Assumed
Solar Photovoltaic Variables			
3.	Photovoltaic capacity per unit area	833 kW/hectare	Solar Energy Corporation of India
4.	Expected annual plant load factor (PLF)	20%	Renewable Energy Tariff Regulation 2020, Central Electricity Regulatory Commission (CERC)
5.	Auxiliary consumption of the PV system	0.75%	Renewable Energy Tariff Regulation 2020, Central Electricity Regulatory Commission (CERC)
6.	Power consumption by the farmer for irrigation of the farm	7000 kWh/yr	(Singh *et al.,* 2022)
7.	Annual PV panel degradation	0.5%	Central Electricity Regulatory Commission (CERC)
8.	Transmission losses	1%	Assumption
9.	Cost of PV Installation	45,000 ₹/kW	Benchmark cost for grid-connected rooftop solar power plants as per Ministry of New & Renewable Energy OM No. 318/33/2019 dated 16 Jul 2019
10.	Operating cost of solar PV system	700 ₹/kW/yr	Explanatory memorandum for CERC Draft (Terms and Conditions for Tariff Determination from Renewable Energy Sources) (Fifth Amendment) Regulations, 2016
Financial Variables			
11.	Debt equity ratio	70:30	Assumption
12.	Cost of debt	9.40%	Rate of interest offered by the Indian Renewable Energy Development Agency (IREDA) to Grade III borrowers for solar rooftop projects
13.	Power export price	3.7 ₹/kWh	Average solar tariff across Indian states that have a feed-in tariff
14.	Capital subsidy	₹94,822	Central Financial Assistance (CFA)/ Central Government Subsidy for rooftop solar plant installed, Ministry of New and Renewable Energy, Govt. of India
Agricultural Variables			
15.	The annual yield of *rabi* crop (wheat) harvested by the farmer	3568 kg/hectare	Economic Survey of India, 2023-24
16.	Input cost for the cultivation of wheat	10.11 ₹/kg	(Srivastava *et al.,* 2017)
17.	The sale price of wheat	22.00 ₹/kg	Economic Survey 2023-24
18.	Reduction in yield of wheat due to shading from PV panels	8%	(Dupraz *et al.,* 2011)
19.	The annual yield of *kharif* crop (maize) harvested by the farmer	3433 kg/ha	Economic Survey of India 2023-24
20.	Input cost for the cultivation of maize	12.96 ₹/kg	(Srivastava *et al.,* 2017)
21.	The sale price of maize	20.26 ₹/kg	MSP for Crops as per Economic Survey 2023-24 (Table 4.5)
22.	Reduction in yield of maize due to shading from PV panels	8%	Assumed the same as that for wheat in the absence of any studies on maize

Table 2. Result of base case analysis

Parameter	Value
Net present value (₹)	1,124,262
Internal rate of return	15.55%
Average debt service Coverage ratio	1.53
Payback period	6 years

shading on the crop yield may be negative or positive depending on the crop type and climatic conditions. Kwon *et al.,* (2020) conducted a study for seven different locations under different climatic conditions and reported that when 63-73% of the sunlight was available to lettuce the yield was 81-99% of the normal yield. Whereas biomass of maize stover was 4.9% higher compared to that without

PV panels. Secondly, the expected income from the sale of solar power is much higher than the income from the sale of agricultural produce. For an acre of grape farm in India, with ground coverage of 0.26 by PV panels, the annual average revenue increased by over 15 times (Malu *et al.,* 2017).

Cultivation of crops under the solar PV panels may also result in higher power generation by the PV panels due to the cooling effect provided by crops. The daily power generation has been observed to be 17.96% higher as compared to the conventional ground-mounted solar PV plants (Waghmare *et al.,* 2023). A case study of *Aloe vera* cultivation under solar PV in North-Western India provided a comparison of the Net Present Value of different options such as cultivation, solar off-grid, solar grid separately, and in combination. The highest NPV was found for combined cultivation and grid-connected solar PV (Ravi *et al.,* 2016). However, the aspect to be emphasized here is that the analysis assumes the debt-equity ratio of 70: 30, which means that for 1-ha land with 25% photovoltaic coverage, the farmer is required to put in the equity of ₹2,716,553 assuming that capital subsidy of ₹94, 822 is available for the agro photovoltaic systems just like solar rooftop projects. Such an amount of funds may not be available to a farmer. The increased cost of infrastructure in such systems has already been recognized as one of the major disadvantages of APV systems (Benghida and Sabrina, 2019). This can pose a major challenge for the uptake of this system. Therefore, there is a need to identify options that can support the farmer with the equity investment needed for the system. This can be done through various options such as the provision of a higher amount of capital subsidy or providing a higher percentage of the debt thereby reducing the quantum of the equity.

Sensitivity

To understand the performance of the system with changes in the key assumptions and also to identify the parameters to which the system is most sensitive, the sensitivity analysis was conducted against the percentage reduction in the agricultural yield, debt percentage, cost of debt, and power export price. The results of the sensitivity analysis have presented in Table 3.

The sensitivity analysis demonstrates that the project remains viable with an IRR of 13.92% even with a debt percentage of 60%. And with a debt percentage of 80%, the IRR is as attractive as 19.01% however the DSCR becomes 1.34 which may not be an ideal condition for the repayment of the debt. The cost of debt is another important factor for the financial performance of the project. The interest rate of the solar project financed by the Indian Renewable Energy Development Agency (IREDA) varies between 8.90% to 9.90%. The project remains financially viable even with the rate of interest of 9.90% giving an IRR of 14.35% and DSCR of 1.48. As expected, since the reduction in the yield of the agricultural output does not have a major impact on the project financials, the sensitivity is also low concerning the percentage reduction in yield. Even with a reduction of 20% in the yield which could be tolerated by a farmer (Weselek *et al.,* 2019), the IRR is 15.05% which should be easily acceptable for any investor. Also, the performance of the APV system for

Table 3. Results of the sensitivity analysis

Reduction in yield (%)	5%	8%	10%	15%	20%
Net Present Value (₹)	1,145,904	1,124,262	1,109,835	1,073,766	1,037,697
IRR (%)	15.68%	15.55%	15.47%	15.26%	15.05%
Average DSCR	1.53	1.53	1.52	1.52	1.51
Payback Period (yrs)	5	6	6	6	6
Debt Percentage	60%	65%	70%	75%	80%
Net Present Value (₹)	1,199,823	1,162,042	1,124,262	1,086,482	1,048,702
IRR (%)	13.92%	14.61%	15.55%	16.91%	19.01%
Average DSCR	1.78	1.64	1.53	1.42	1.34
Payback Period (yrs)	6	6	6	5	5
Cost of Debt	8.90%	9.15%	9.40%	9.65%	9.90%
Net Present Value (₹)	1,315,358	1,220,109	1,124,262	1,027,824	930,802
IRR (%)	16.72%	16.14%	15.55%	14.96%	14.35%
Average DSCR	1.57	1.55	1.53	1.50	1.48
Payback Period (yrs)	5	5	6	6	6
Power Export Price (₹/kWh)	3	3.4	3.7	4	4.3
Net Present Value (₹)	804,561	297,624	1,124,262	1,950,901	2,777,540
IRR (%)	1.22%	10.15%	15.55%	20.45%	25.05%
Average DSCR	1.24	1.40	1.53	1.65	1.77
Payback Period (yrs)	14	7	6	5	4

crop yield mainly depends on the crop variety and its ability to absorb light in a shaded environment (Willockx *et al.,* 2020). On the contrary under very dry conditions, the grain yield was observed to be higher under the APV system (Amaducci *et al.,* 2018). Indian Council of Agricultural Research (ICAR) has shown that APV systems have the potential to increase crop yields by up to 30% while also generating renewable power (Mohammad *et al.,* 2024). The light saturation point is defined as the maximum amount of light that a plant can use for photosynthesis. Therefore, solar panels above the crop should allow penetration of at least the light intensity equal to this saturation point (Guerin, 2019). The crop species with low light saturation points are suitable for cultivation under PV (Kadowaki *et al.,* 2012).

More importantly, the project's financials are highly sensitive to the power export price or the price at which the generator or the farmer in this case can sell its electricity to the power distribution company. The NPV of the system is most sensitive to the electricity price, capacity factor, capital expenditure, and discount rate (Proctor *et al.,* 2021). At the power export price of ₹3.4 per unit, the project becomes less viable with an IRR of 10.15% and at ₹3.0/unit the IRR is 1.22%. Therefore, to keep the project viable for the farmer and the financer, it is crucial to provide a suitable feed-in tariff for such projects. Another crucial condition to keep the project financially viable is to ensure an appropriate price for the power being fed to the grid by the system. A power export price of less than ₹3.6 per unit makes the project unviable. Therefore, feed-in tariffs for the agro photovoltaic systems will have to be ensured to encourage farmers to adopt and provide comfort to the financing agencies.

Limitations of the study

The study is an attempt to understand the financial performance of a typical APV system in India from the farmer's perspective. However, the following are the major limitations of the study:

- The analysis assumes a certain PV capacity per unit area. However, with the latest advancements in technology and capacity per unit area can be higher which can further improve the project performance.
- For analysis, only two crops have been considered in a year (wheat in the *rabi* season and maize in the *kharif* season). There can be more crops in during the reason. Also, the yield per unit area and sale price of the crop have been taken from the economic survey which may be on the conservative side.
- It has been assumed that the installation of PV panels on the crop will reduce the yield, based on the studies conducted in temperate/colder conditions. However, in a tropical country like India, the shading provided by the PV panels may result in higher yield for some of the crops due to protection from the harsh sun lower evapotranspiration during the summer season, and temperature moderation during the winter season. This is because photosynthesis takes place in the temperature range of 22 °C to 25°C, outside this range, photosynthesis reduces to a significant extent (Ezzaeri *et al.,* 2018).

Hence, there is further scope for improvisation of the analysis which may give even better results concerning the financial performance of the APV systems. Furthermore, research on the financial performance of different kinds of crops such as vegetables, fruits, and ornamental crops should also be taken up for further upscaling of APV systems. Overall the agro photovoltaic system in one ha with photovoltaic panel coverage of 25%, is a viable project with the basic assumptions and also under most sensitivity conditions. It substantially increases the cash flow and income diversification. However, the major challenge in the large-scale deployment of this APV is the high upfront equity investment required for the installation of the system. Provision of enhanced capital subsidies to the farmers for installation of APV systems and project financing with a higher percentage of debt and development of business models through the energy service companies to take care of the high initial investment can overcome these challenges.

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