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TECHNO-ECONOMIC ANALYSIS OF AGRI-VOLTAICS DESIGNS: A CASE STUDY OF DISTRICT BADIN

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Abstract: Ground-mounted PV is used as a renewable source to mitigate the use of fossil fuels, decrease the chances of depletion of fossil fuels globally, and protect the environment from greenhouse gases. But it is resulting in a decrease in crop and agricultural land. As land is an essential part of life, it provides fresh water, food, and many other resources related to ecology. Because of different infrastructures, industrial development, and economic purpose buildings, as well as because of land desertification and degradation of soil, it is expected that cropland may decrease globally. Due to increasing Population and to fulfill the basic needs, it is essential need to take a way which leads towards sustainable solution to meet the energy food and water demand. The combination of Agriculture and Solar PV termed as "Agri-Voltaics "can be the sustainable solution to overcome above problems. This study explores the economic viability of Agri-voltaic systems, focusing on combining tomato cultivation with solar energy generation in Badin District. Two scenarios are compared, with Scenario 2 considering increased tomato yields under solar panels. Results reveal that Scenario 2 surpasses Scenario 1, boasting an impressive internal rate of return (IRR) of 85.67%, a substantial present value (PV) of Rs 13,890,821.67, a net present value (NPV) of Rs 12,390,821.67, and a rapid payback period (PBP) of just 1.17 years. These findings highlight the immense potential of Agri-voltaic systems as a lucrative and sustainable agricultural practice in Badin District, offering simultaneous benefits for food security, renewable energy production, and dual use of land.

Keywords: *Agri-voltaics, Dual use of land, Tomatoes, Badin, Solar PV, Techno-Economic Analysis*

1. Introduction

Alternative energy sources are needed to fulfill rising demand in a sustainable and environmentally friendly manner. Due to its enhanced efficiency, longevity, cost-effectiveness, and adaptability, photovoltaic (PV) technology is becoming more and more significant in the shift towards low-carbon economies. A growing number of creative options for installing PV while minimizing related land use are becoming more significant. Some of these novel examples are building integrated photovoltaic systems (which use existing building surfaces), floating photovoltaic systems (which use existing water surfaces), and Agri-voltaic systems (which use land for both food and energy). In 1982, Adolf Goetzberger, who founded the Fraunhofer Institute in 1981 with Armin Zastrow, proposed a dual use of arable land for solar energy generation and plant cultivation, which would solve the problem of arable land competition between solar energy production and crop production.[1] Agri-voltaics is the combination of agricultural and solar photovoltaic on the same piece of land. Due to the abundance of fairly flat land in rural farmlands, ground-mounted solar projects are common. In reality, installing solar panels on less than 1% of the world's crops would be sufficient to power the entire planet. [2] The goals and benefits of a solar dual-use or Agri-voltaic systems are defined by a broad look into this perspective: Solar power generation and agricultural output are purposely combined on the same land plot to reduce land-use conflicts and gain socio-economic benefits over the single-use of both applications.

Figure 1: Dual Use of Land

Because of the lower structure-related cost and the microclimate formed under the solar modules, crops can grow in between the rows of PV arrays under and around the modules, depending on plant height and light needs. As a result, shade-tolerant plants can be used in the space beneath modules, especially in hot arid areas. In India, some research

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has already been done in this area [3][4]. Solar arrays (stripes) over crops aren't the only way to combine farming and energy generation on the same location. From all over the world has shown crop yields increase when the crops are partially shaded with solar panels. These yield increases are possible because of the microclimate created underneath the solar panels that conserves water and protects plants from excess sun, wind, hail and soil erosion. This makes more food per acre, and could help bring down food prices. Many crops grown here, including corn, lettuce, potatoes, tomatoes, wheat and pasture grass have already been proven to increase with Agri-voltaics [5].

District Badin is a trading Center for tomatoes in Sindh and contributes a lion share among the tomato cultivating zones; i.e. Badin, Karachi, Mirpurkhas and Hyderabad. In Sindh, tomatoes are grown on an area of 8.7 thousand hectares from which 33.00 thousand hectares are grown under Badin district [6].

Badin District with geographical coordinates 24.724370°, 68.874570° (24°43'28", 068°52'28") has a solar potential

Monthly averages *of Solar Irradiations of District Badin*	
Unit	kWh/m²
Jan	158
Feb	155.5
Mar	177.2
Apr	173.2
May	160.9
Jun	117.2
Jul	65.3
Aug	72
Sep	122.6
Oct	168.1
Nov	145.3
Dec	151.6
Yearly	1666.9

Table 1: Site Information Using Solar Atlas. [7]

This research aims to conduct a rigorous techno-economic analysis of Agri-voltaic designs, specifically investigating the potential of growing tomatoes under solar panels. The study seeks to determine the practicality and profitability of implementing these innovative Agri-Voltaic systems.

2. Related Work:

Various research studies have been done towards the Agri-Voltaics on different aspects like concept, efficiency, design, Technical Parameters etc; some literature reviews are as under:

Sekiyama & Nagashima [8] deployed a stilt-mounted solution to a maize crop with two different density configurations and discovered that the low-density configuration yields 5.6 percent more biomass than the controlled one. However, this study is only limited for single crop.

Aside from these pilot projects, agri-voltaics has sparked a lot of interest in the research community, which is looking into the potential from various disciplinary perspectives and practical issues, such as solar power potential by land cover type (croplands, grasslands, and wetlands) [9]

Some studies related to Agri-Voltaics highlights water use efficiency in drylands [10] or groundwater stressed regions [11].

Currently, the effectiveness of agri-voltaic systems in terms of crop compatibility is evaluated based on the biomass yield priority, which is directly related to the possible market value benefit.

Pearce & Dinesh[12] indicate that the crop selection process is based on the correlation between the plant's light requirements, which are established by its light saturation point or shadow tolerance, and the percentage of shade that the photovoltaic system provides.

Japan has identified a list of the most significant agri-voltaics crops appropriate for the Japanese setting through a repository gathered by Chiba University; more than 120 species are grown under agri-voltaics farms around the nation.[13], providing a showcase of successful growth that have contributed to the merging of these systems in the country. Similarly, the Japanese Solar Sharing Network [14] gives a list of plants along with growth recommendations based on the light saturation threshold of the crop.

Crop shadow tolerance and biomass yield are related, but there are a lot of factors that seem to affect how well an agri PV system works. Studies have indicated that crops that are shade-intolerant and equipped with PV buildings on stilts yield more than crops planted in full sun.

Therefore, production in 2017 was lower than in 2018, when a hot summer led to higher yields of +3%, +11, and +12% for wheat, potato, and celery, respectively, and barely affected clover grass with minus 8% under the identical system design. Production in 2017 was therefore reduced by 19% for wheat, 18% for potato, 19% for celery, and 5% for clover grass [15].

A team of researchers [16] uncovered that the levelized cost of electricity (LCOE) for Agri-photovoltaic (APV) differs from that of traditional ground-mounted photovoltaic systems. Their study, which included an interdisciplinary analysis of APV in Germany, revealed that the LCOE of APV is 38% higher than that of ground-mounted PV. This finding translates to an annual farmland preserving cost of €9,052 per hectare under APV.

Cu Thi Thanh Huyen (2021) used REtScreen Software to analyze the economic effectiveness of a typical solar power project on agricultural land in Vietnam's Gia Lai Province, which reveals an 8-year payback time. [17]

3. Methodology:

3.1 Experimental setup:

The experimental arrangement includes a Solar Panel: SOLARPRO MONO 150W with 36 cells (9 × 4), supported by a structure constructed from wood and bricks. The experiment was took place in Agricultural Land in District Badin, where tomato seeds were sown. This setup is integral to a study investigating the techno-economic aspects of Agri-voltaic designs, with a specific emphasis on the viability of tomato cultivation under solar panels.

Figure 2: Experimental Setup

The Agri-voltaic system is designed with adaptable technical specifications. Its solar panels can be manually adjusted to tilt between 20 and 30 degrees, allowing for optimal sun exposure. The setup receives solar irradiations of 177 kWh/m² per year, providing ample energy for plant growth. Additionally, the photovoltaic (PV) system's height is adjustable, ranging from 2 to 3 feet, ensuring flexibility in installation and maintenance.

The study conducted in District Badin from January to July 2023 focused on comparing the yield of tomato plants grown under solar panels to those grown without solar panels. The results showed that the plants under the solar panels yielded approximately 1.5% more than the plants without solar panels. Specifically, the yield of tomatoes under the solar panels was 5kg, while the yield from the other case was 3kg. This suggests that the use of solar panels in agriculture could have a positive impact on crop yield, potentially increasing overall productivity. Below figure shows the yield difference for case 1 and case 2 that are; yield of tomatoes without solar panel and yield of tomatoes under solar panel respectively.

Figure 3: Case 1 and Case 2

3.2 Economic Equations:

In this study, equations will be used to conduct a detailed analysis of the economic aspects of Agri-voltaic designs. This involves examining various economic factors to understand if implementing Agri-voltaic systems, such as growing tomatoes under solar panels, is financially viable and beneficial. The analysis aims to provide a clear picture of the economic implications and advantages of integrating Agri-voltaic systems into agricultural practices**.**

1. Pay Back Period = initial investment/ Net cash flow
2. $Total\ Investment\ peracre = solar\ investment + Agicultural\ invetment$
3. $Internal\ Rate\ of\ Return(IRR) = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n}$
4. $Net\ Present\ Value(NPV) = \sum_{n=0}^{N} \frac{\acute{C}_n}{(1+r)^n}$

Figure 4: Economic Indicators [11] [16]

Two scenarios are being evaluated for the techno-economic analysis of a 1-acre agricultural land area under specific, predefined conditions, i.e. for District Badin.

Scenario 1: involves setting up 50 solar panels, each capable of generating 150 watts, on a 1-acre tomato field. This scenario does not take into account any possible increase in tomato yield that may result from the solar panels' presence.

Scenario 2: Scenario 2 involves the installation of 50 solar panels, each with a capacity of 150 watts, over a 1-acre tomato field. This scenario considers a 1.5 times increase in tomato yield under the solar panels compared to the yield without solar panels.

3.3 Agricultural Output:

Scenario 1: the tomato yield is 40 bags per day, each weighing 10kg, totaling 400kg daily. Considering 20 picking days, this amounts to 800 bags. At an average price of 800 Rs per bag, the total revenue per acre is 640,000 Rs.

Scenario 2: Experimental findings indicate that the yield of tomatoes under a solar panel is 1.5 times higher than without a solar panel. The estimated increase in yield under a solar panel is calculated as follows: 1.5 times the initial yield of 3kg, resulting in 5kg. This represents a 2kg increase per day. Over the 20 picking days, this amounts to 200kg additional yield. Consequently, the total daily yield under the solar panel is 600kg (400kg + 200kg). This leads to a total of 1200 bags over 20 picking days. Assuming an average price of 800 Rs per bag, the total earnings per acre are calculated as 1200 bags x 800 Rs, totaling 960,000 Rs

3.4Total Investment per Acre:

The total investment per acre comprises both agricultural and solar-related costs. Specifically, for the solar investment, the cost breakdown is as follows: the cost of a 150 watt solar panel is 16,000 Rs, totaling 800,000 Rs for 50 solar panels. Additional expenses for support and other items amount to 500,000 Rs. Thus, the total solar investment sums up to 1300,000 Rs. When combined with the agricultural investment of 200,000 Rs, the total investment per acre comes to 1,500,000 Rs.

4. Results and Discussion:

In the first scenario of this research, the techno-economic analysis reveals highly favorable outcomes for Agri-voltaic systems:

- Internal Rate of Return (IRR): 64.33%

- Present Value (PV): Rs. 10,431,628.72

- Net Present Value (NPV): Rs. 8,931,628.72

- Payback Period (PBP): 1.55 years

These results underscore the strong economic viability of implementing Agri-voltaic systems for cultivating tomatoes under solar panels, highlighting its potential as a sustainable and profitable agricultural practice.

Year	Revenue on the basis of Electricity from PV Panel	Revenue on the basis of Product Yield	Running Expenses	COS (Cost of Sales)	Cum. Earn
Year 0	*Investment:*				-1,500,000
Year 1	525000	640000	200000	200000	-535,000
Year 2	525000	640000	200000	200000	430,000
Year 3	525000	640000	200000	200000	1,395,000
Year 4	525000	640000	200000	200000	2,360,000
Year 5	525000	640000	200000	200000	3,325,000
Year 6	525000	640000	200000	200000	4,290,000
Year 7	525000	640000	200000	200000	5,255,000
Year 8	525000	640000	200000	200000	6,220,000
Year 9	525000	640000	200000	200000	7,185,000
Year 10	525000	640000	200000	200000	8,150,000
Year 11	525000	640000	200000	200000	9,115,000
Year 12	525000	640000	200000	200000	10,080,000
Year 13	525000	640000	200000	200000	11,045,000
Year 14	525000	640000	200000	200000	12,010,000
Year 15	525000	640000	200000	200000	12,975,000
Year 16	525000	640000	200000	200000	13,940,000
Year 17	525000	640000	200000	200000	14,905,000
Year 18	525000	640000	200000	200000	15,870,000
Year 19	525000	640000	200000	200000	16,835,000
Year 20	525000	640000	200000	200000	17,800,000
Year 21	525000	640000	200000	200000	18,765,000
Year 22	525000	640000	200000	200000	19,730,000
Year 23	525000	640000	200000	200000	20,695,000
Year 24	525000	640000	200000	200000	21,660,000
Year 25	525000	640000	200000	200000	22,625,000
Year 26	525000	640000	200000	200000	23,590,000

Figure 5: Values for Scenario 1

And after conducting the techno-economic analysis, the final results for scenario 2 are as follows:

- Internal Rate of Return (IRR): 85.67%

- Present Value (PV): Rs 13,890,821.67

- Net Present Value (NPV): Rs 12,390,821.67

- Payback Period (PBP): 1.17 years

These results indicate that scenario 1, which involves implementing Agri-voltaic systems for growing tomatoes under solar panels, is a highly profitable and viable investment option. The high IRR, substantial PV and NPV, along with a short PBP, demonstrate the economic feasibility and potential benefits of adopting Agri-voltaic designs in agricultural practices.

Time	Revenue on the basis of Electricity from PV Panel	Revenue on the basis of Product Yield	Running Expenses	COS (Cost of Sales)	Cum. Earn
Year 0	Investment				-1,500,000
Year 1	525000	960000	200000	200000	-215,000
Year 2	525000	960000	200000	200000	1,070,000
Year 3	525000	960000	200000	200000	2,355,000
Year 4	525000	960000	200000	200000	3,640,000
Year 5	525000	960000	200000	200000	4,925,000
Year 6	525000	960000	200000	200000	6,210,000
Year 7	525000	960000	200000	200000	7,495,000
Year 8	525000	960000	200000	200000	8,780,000
Year 9	525000	960000	200000	200000	10,065,000
Year 10	525000	960000	200000	200000	11,350,000
Year 11	525000	960000	200000	200000	12,635,000
Year 12	525000	960000	200000	200000	13,920,000
Year 13	525000	960000	200000	200000	15,205,000
Year 14	525000	960000	200000	200000	16,490,000
Year 15	525000	960000	200000	200000	17,775,000
Year 16	525000	960000	200000	200000	19,060,000
Year 17	525000	960000	200000	200000	20,345,000
Year 18	525000	960000	200000	200000	21,630,000
Year 19	525000	960000	200000	200000	22,915,000
Year 20	525000	960000	200000	200000	24,200,000
Year 21	525000	960000	200000	200000	25,485,000
Year 22	525000	960000	200000	200000	26,770,000
Year 23	525000	960000	200000	200000	28,055,000
Year 24	525000	960000	200000	200000	29,340,000
Year 25	525000	960000	200000	200000	30,625,000
Year 26	525000	960000	200000	200000	31,910,000

Figure 6: Values for Scenario 2

4.1 Comparison of Scenario 1 and 2:

Scenario 2 demonstrates superior financial performance compared to scenario 1 in the techno-economic analysis. It exhibits a higher Internal Rate of Return (IRR), indicating a more favorable return on investment. Additionally, scenario 2 boasts higher Present Value (PV) and Net Present Value (NPV), reflecting greater profitability over time. Furthermore, scenario 2 features a shorter Payback Period (PBP), suggesting a quicker recovery of the initial investment. These findings collectively suggest that scenario 2 is a more economically viable for Agri-voltaic systems for tomato cultivation, and that increase in yield in scenario 2 is practically possible and practically proved.

5. Conclusion:

This study concludes that Agri-voltaic systems, particularly the cultivation of tomatoes under solar panels, are economically viable and beneficial and practically possible, especially in the context of Badin District. Scenario 2, which includes an increase in tomato yield under solar panels, demonstrates superior financial performance compared to Scenario 1. With higher Internal Rate of Return (IRR), Present Value (PV), Net Present Value (NPV), and a shorter Payback Period (PBP), Scenario 2 highlights the potential of Agri-voltaic systems as a sustainable and profitable agricultural practice in Badin District. These findings emphasize the dual benefits of Agri-voltaic systems, as they contribute to both food security and renewable energy generation. This highlights their potential as a compelling solution for sustainable agriculture and energy production, enabling the dual use of land in Badin District and similar regions.

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