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Impact of Cultivating Vegetables and Spices under Solar PV Modules

Policy Advisory for Promoting Energy Efficiency and Renewable Energy (PAP) project

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Registered offices
Bonn and Eschborn, Germany

GIZ Bangladesh
PO Box 6091, Gulshan 1
T + 880 2 5506 8746-52
F + 880 2 5506 8753
E giz-bangladesh@giz.de
I www.giz.de/bangladesh

Project:
Policy Advisory for Promoting Energy Efficiency and Renewable Energy (PAP)

Author.:
Dr. Muhammad Humayun Kabir

Review & Input:
Shahbina Nahid Labib
Md Abdul Gaffar

On behalf of
German Federal Ministry for Economic Cooperation and Development (BMZ)

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Executive Summary

Bangladesh achieved 100% electrification in 2022. The government is now focusing on diversifying fuel sources for electricity generation by adding more clean energy. The goal is to produce 40% of the country's power from renewable energy sources by 2041. However, development of renewable energy requires vast land which is a challenge for Bangladesh as the country's population is increasing and cultivable land is decreasing. In such a condition Agri-PV may be a good solution. In this context, with the technical assistance of GIZ and Spectra Solar Park, the present study entitled the impact of cultivating vegetables and spices under solar PV modules has been undertaken. The objective of the study is to conduct an analysis and compare the performance of crops between beneath the solar PV modules and open space, to assess the performance and impacts of crops under solar PV models and to identify the reasons behind the performance of vegetables and spices under solar PV modules. The experiment was set up in the Spectra Solar Park of Manikganj district. The location is 53 Km away from the capital city Dhaka. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Five different crops among which two vegetables (Eggplant and Okra), and three spices (Chili, Turmeric and Ginger) cultivated under solar panel compared with control where solar panel was absent. The selection of crops is done based on the shade tolerance capacity, project implementation time and crop season. The area of the experimental plot was divided into equal blocks with 3 replications in each treatment. The size of each unit plot was 3.5 m × 2 m. Soil sample and crop data (growth and development) were collected and analyzed. Soil analysis revealed that the soil is sandy and the organic carbon and other macro and micronutrients are very low.

It was observed that up to one and half months the performance of Eggplant, Okra, Ginger and Turmeric in beneath the solar PV modules and Eggplant, Okra and Turmeric in open space was almost similar with the performance of usual cultivated land. However, after this period the performance of Eggplant and Okra in both places were gradually decreasing. Finally, it was observed that the performance of Ginger and Turmeric under the solar PV modules and Eggplant and Turmeric in open space showed about normal yield. The probable reasons for failure of normal growth and yield of the selected crops under the solar PV modules are soil type, temperature and shade. From the findings it can be said that Ginger and Turmeric may be a good choice to cultivate under the solar PV modules. The experiment was laid out with few summer crops and limited area. Therefore, further experiment with winter vegetables and crops that are suitable for sandy soil should be conducted.

List of Abbreviations

Abbreviation	Description
Agri-PV	Agri-Photovoltaics
DLI	Daily Light Integral
V	Volt
KV	Kilo Volt
AC	Alternating Current
DC	Direct Current
CSA	Climate Smart Agriculture
GHG	Green House Gas
BCR	Benefit Crop Ratio
BDT	Bangladeshi Taka
SPI	Solar Pump Irrigation
FG	Farmers Group
RE	Renewable Energy

Table of Contents

1. Introduction

a. Background and Rational

Bangladesh achieved 100% electrification in 2022. The government is now focusing on diversifying fuel sources for electricity generation by adding more clean energy. The goal is to produce 40% of the country's power from renewable energy sources by 2041 (STEAG, 2023). Development of Renewable Energy (RE) generation facilities, especially solar and wind require vast land. Bangladesh being an agrarian and a densely populated country that is dependent on agriculture and related activities, the availability of land for other purposes becomes a challenge. According to World Population Review 2022 statistics, Bangladesh is the 11th most densely populated (1138/km^2) country in the world. Bangladesh faces a decrease in available land, creating a significant challenge for renewable energy development. Ground-mounted solar PV power plants require large open spaces, making land scarcity a major issue. Additionally, due to Bangladesh's rich agricultural history, national policy prohibits using arable land for solar photovoltaic installations, further hindering solar PV development in the country (STEAG, 2023).

To address land consumption challenges associated with solar PV projects, especially in land-scarce countries like Bangladesh, renewable energy experts and researchers are exploring innovative solutions. Considering the land crunch, it would be prudent and the need of the hour to co-locate the land extensive RE based power plants that are used not only for power generation but also for farming to sustain the economy of the country. With this background the Government of Bangladesh (GoB) is examining the option of multipurpose use of land for electricity generation through renewable sources and suitability of crop cultivation. The option of using land for development of RE projects as well as for farming can be an ideal solution for balancing the energy and food security need of the country. In this context, a study to determine the cultivation of shade tolerance crops under solar PV Module is necessary. Feeling the necessity, a study to determine the impact of cultivating specific vegetables and spices under solar PV module has been taken. The performance of selected vegetables and spices under the solar PV module compared to open space has been determined. In addition, based on crop performance and electricity production, economic analysis was done and a suitable business model for implementing Agri-PV approach has been proposed. The study is implemented by GIZ with the assistance of Spectra Solar Park Ltd, Manikgonj. The findings of the study may be helpful to formulate polices to implement Agri-PV program in Bangladesh.

b. Objectives of the study

1. To assess the impact of Eggplant, Okra, Chili, Ginger and Turmeric cultivation under solar PV modules
2. To compare among these vegetables and spices regarding their performance and production in solar PV modules
3. To identify the reasons behind the performance of vegetables and spices under solar PV modules

2. Understanding Agri-PV

a. What is Agri-PV?

Agri-PV or Agri-photovoltaics consists of using the same area of land to generate both solar energy and agricultural products.

Agrivoltaics refers to the innovative integration of solar photovoltaic systems and agriculture, which allows for the simultaneous production of food and renewable energy. This approach is significant as it can increase land use efficiency, increase crop yields, and improve the performance of solar panels by providing a cooler microclimate (Barua et al., 2023; Patel et al., 2023).

It is a promising solution for addressing the growing demand for food and energy in the face of climate change, land scarcity, and rising populations (Rahman et al., 2023).

b. Design consideration for Agri PV

There could be two broad approaches to developing agrivoltaics projects:

(A) A brownfield agrivoltaic project – Planning for utilization of existing solar power plant sites for agricultural purposes and selecting crops that will be suitable for the site and can co-exist with the solar power plant without impacting its performance and with no significant changes or investment required.

(B) A greenfield agrivoltaic project – A new site where a PV power plant and agricultural activities are planned together. Such sites may already be used for agricultural purposes and PV power plants are planned to use the land for dual purposes (agriculture and energy) to enhance productivity.

For both approaches, the following fundamental considerations are necessary for designing an agrivoltaic project (Barua et al., 2023).

1. Structure and crop height:

It is necessary to match crop height to a mounting structure of a PV power plant to avoid hindrance to crop growth and any shadow on the PV modules.

2. Access to sunlight:

Solar fields (placement of PV arrays) and agricultural fields shall be placed so crops get adequate access to sunlight according to their DLI (daily light integral) requirement. As different zones in the solar field site will have different levels of sunlight, crops shall be selected based on minimum DLI requirements and sunlight availability due to shading from PV modules.

3. Safety of personnel:

In solar power plants, PV modules are connected in series, resulting in a DC voltage of 300 V to 1500 V, depending upon the size of the plant and the type of inverters used. The string and array cables carrying such voltage are laid across the solar field and mounting structure. Similarly, the output of PV inverters is around 400 V AC, which will be further stepped up to 11 kV or 33 kV in a utility-scale plant. Exposure to such voltages is hazardous and fatal. In an agrivoltaic setup, in addition to the personnel working for the power plant, other personnel will also be involved in agricultural activities. Therefore, utmost care must be taken in designing electrical safety considerations for agrivoltaic projects.

4. Safety of power plant and equipment:

The life and performance of PV power plant and equipment can be affected due to electrical faults (such as over current/over voltage/arcing), mechanical damage (damage of cables/PV modules/structure) and poor maintenance practice. In an agrivoltaic setup, PV plants will be exposed to multiple agricultural activities during sowing, nursing and harvesting. Depending upon the method of sowing/nursing/harvesting and tools and equipment used for such activities, the risk of mechanical damage is to be assessed, and appropriate measures considered in the design for the protection of PV modules, cables and other equipment.

5. Design optimization for cost:

To achieve the desired return on investment, carrying out a life cycle cost benefit analysis for agrivoltaic projects, particularly greenfield projects is essential. Based on the priority of expenditure vs. income for the project life cycle, the design approach should be optimized for maximum return on investment (Barua et al., 2023).

c. Advantages and Potential of Agri-PV

According to Trommsdorff et al., (2024), the advantages and potential of Agri-PV are as follows.

Advantages of Agri-PV

- Combines agriculture and ground-mounted PV systems
- Offers additional benefits for farming, including protection against storm, hail, frost and drought damage
- It has a lower level of electricity (LCOE) compared to small rooftop PV systems
- It creates an additional source of revenue for the farmers by the sale of power
- A portion of the energy produced by the plant can be used to power pumps, irrigation systems etc. thus reducing the energy cost.

Potential of Agri-PV

In the Agri-PV technology, a field can be dual purpose: to grow crops (photosynthesis) and generate solar power (photovoltaics). The technical solutions for integrating PV into farming are as diverse as farming itself. They can be broadly categorized into open and closed systems. Closed systems mainly cover PV green houses, while open agrivoltaic systems can be broken down into ground-level, interspace PV and stilted, overhead PV. In the overhead systems, the land under the PV modules is used for farming, whereas with interspace systems, it is usually the land between PV modules that is farmed. The main benefits of interspace systems are that they have lower costs and tend to impact the landscape less. Overhead installations, on the other hand, use the land more efficiently and can give crops greater protection against adverse environmental effects. Certain interspace system concepts can also provide protection against storm damage and excessive evaporation.

d. Business models

Because agrivoltaic systems incorporate agricultural land, the business models are often more complex than for ground mounted PV. Depending on the parties involved in the project, its implementation can often involve different players or areas of responsibility with different functions. Some business models are mentioned below (Krishnan, 2023).

Business model 1: Government Owned

Business model 2: Developer Owned

Business model 3: Farmer/FG Owned

Business model 4: Shared Ownership (Farmer/FG + Developer)

e. Environment and sustainability

The Agri-PV approach has potential in the context of environment and sustainability. In this context, some points are highlighted below.

1, Water conservation in irrigation

Around 80% of water resource is used by the agriculture sector alone. Farmers are too dependent on groundwater for irrigation, leading to table lowering of the water table (Jain et al., 2019; Harsha, 2017). A recent study in agrivoltaics at the Oregon State University, Corvallis campus reveals that the water conversation improved by 328% due to solar panels (Adeh et al., 2018). The conservation of water happened due to solar panels acting as a barrier to water evaporation. The same is evident from the study conducted in Montpellier, France (Marrou et al., 2013).

2. Reduce the pesticide usage in agriculture

The overuse of pesticides and fertilizers harms the soil and environment (Sharma and Singhvi, 2017). Agrivoltaics were reported to reduce pesticides in some preliminary research. According to an experiment conducted in the Negev Desert, agrivoltaics consisting of monofacial solar panels enabled reducing pesticides in vegetable farming (Weselek et al., 2019). The finding is similar with the study conducted on a farm in the Netherlands (Toledo and Scognamiglio, 2021).

3. Lowering of Greenhouse Gas Emissions

Electricity, agriculture, and construction are the major contributors to greenhouse emissions. With agrivoltaics, additional electricity can be generated, and that will reduce the dependence on coal-based power plants. Agriculture contributes to greenhouse gas emissions due to methane gas produced by livestock (Lal, 2020). The agrivoltaics as a source of secondary income generation ultimately decrease the dependence on livestock, thereby reducing the excessive methane gas production.

4. Climate smart agriculture practice

The Climate smart Agriculture (CSA) aims to achieve three main objectives. The first objective is to increase the productivity of agriculture that translates to an increase in farmers' income. The second objective of CSA is to make the farm yield less vulnerable to aberrations such as natural disasters, pests, diseases, and others. Lastly, the final objective is to reduce GHG emissions by developing technologies that can be used in agriculture (Lipper et al., 2014; Campbell et al., 2012). As Agri-PV approach can fulfill all objectives thus it is treated as CSA approach (Mahto et al., 2021).

3. **Pilot Study on Agri-PV in Manikganj, Bangladesh**

a. Description of the project site

The study was conducted in the experimental field of Spectra Solar Park of the Renewable energy producing unit, Shibaloy, Manikganj, Bangladesh. The location is 53 Km away from the capital city Dhaka. The area of the park is 140 acres with a capacity of 35 MW. The location is between 23.78° north latitude and 89.82° east longitude and 11 m above sea level. The period of the study was from July to November 2024. The average temperature and rainfall in the period are 32° C and 286 mm respectively.

b. Soil conditions

The soil at the experiment site is sandy, containing extremely low organic carbon, nitrogen, potassium, phosphorous and other nutrients (Table 1). Because of sandy texture of soil, its water storage capacity is very low and can be heated soon. The features can be considered as one of the major problems in cultivating crops in the experimental site.

Table 1. Soil organic matter, macro and micronutrients

Item	**Unit**	**Soil under solar PV**	**Soil in open space**
Organic carbon (OC)	(%)	0.29	0.13
Total Nitrogen (TN)	(%)	0.02	0.008
Potassium (K)	(meq/100gm)	0.08	0.08
Phosphorus (P)	mg/kg	0.01	0.02
P^h	-	7.4	7.3
Sulphur (S)	(ppm)	5.8	8.5
Sodium (Na)	(meq/100gm)	0.09	0.07
Zinc (Zn)	Ppm	0.21	0.23
Boron (B)	Ppm	0.002	0.001

c. Preparation for the study

An experienced farmer and Sub-Assistant Agriculture Officer were appointed to cultivate and monitor the crop field. Considering project time, crop season and shade tolerance level, five crops among which two vegetables (Eggplant and Okra) and three spices (Chili, Ginger and Turmeric) were selected to plant. The seedling of Eggplant and Chili, seed of Okra and rhizome of Ginger and Turmeric were planted and sown in the experimental plot. The land was cleared and prepared for sowing and planting with some local instruments like spade, sickle, hand-held hoe etc. As the organic carbon of the study land is very negligible, a higher amount of organic manure applied after the preparation of land. After few days of land preparation, the vegetables and spices were planted. A strong fence was made to protect the crops from dog's and fox's disturbance.

d. Study Methodology (experimental design)

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The layout of the experiment prepared for distributing the crops. Five different crops (Eggplant, Okra, Chili, Ginger and Turmeric) cultivated under solar panels compared with control where solar panels were absent. The area of the experimental plot was divided into equal blocks with 3 replications in each treatment. The size of each unit plot was 3.5 m × 2 m. The standard spacing was maintained for planting the crops. Similar design was maintained in two places (under the solar PV modules and open space).

e. Induction and Safety Training

Safety training was provided to the farmers, officer and supervisor of the experiment to make them aware about potential problems The expert team of Spectra Solar Park provided the training. It was arranged at the beginning of the experiment.

f. Data Collection and Analysis

The researcher collected soil samples and crop data from both locations (under solar PV modules and open space). The soil was tested in the lab of soil science to know the major macro and micronutrients, organic matter, soil pH etc. The researcher also collected data on various crop growth and yield parameters like leaf color, average height, number of active plants, flowering and fruiting in both places (under solar panel and open space). The data collected were analyzed through MS excel.

g. Overall land coverage ratio

The spectra solar park stands on about 140 acres of land among which about 30% area can be brought under crop cultivation. So, 45 acres or 4500 decimal lands can be used for crop cultivation. The experimental land size 2 decimals which were very negligible in comparison to total probable cultivation area.

h. Economic analysis

The study did a profitability analysis of the crops planted in the study site and electricity produced in the plant. The result is shown in Table 2, 3 and 4. Cost, output and Benefit Cost Ratio (BCR) was calculated for the crops in the experimental plot as well as together.

Table 2. Cost and benefit of the crops beneath the solar panel (BDT/ $7m^2$)

Crops	Cost	Output	Net Revenue	BCR	Profitability
Egg plant	290	20	-270	0.06	Loss
Okra/Ladies figure	280	10	-270	0.03	Loss
Chili	310	20	-290	0.06	Loss
Ginger	415	435*	20	1.08	Profit
Turmeric	395	420*	25	1.06	Profit

*= Projected value

Table 3. Electricity production in the Spectra Solar Plant (from July to November 2024)

Months	days	Average Production (KWT/day)	Price (BDT)	Gross Revenue
July, 2024	31	20	14	8680
August, 2024	31	20	14	8680
September, 2024	30	20	14	8400
October, 2024	31	20	14	8680
November, 2024	30	20	14	8400
Total	153			42840

Table 4. Gross revenue from crops and electricity production in July to November 2024

Item	Gross revenue (BDT/decimal)
Crops (Ginger and Turmeric) *	5985
Electricity	42840
Total	48,825

* Considering profitable crops only

i. Proposed Business model.

One of the major challenges in terms of the implementation of agri-PV is the development of suitable business models. The business model depends on the ownership or party involved with Agri-PV. Out of various business models, Shared Ownership (Farmers/FG + Developer) perhaps would be the most appropriate business model for the present study location as well as Bangladesh aspect. Here, a private or public organization will develop the solar panel, and the farmers or farmers group will provide land and labour to engage in the program. The profit will be shared among the two parties based on agreement or contribution. Thus, both parties can benefit economically.

j. Results and Recommendations

1. Impact of crop cultivation under solar PV modules

To assess the impact of Eggplant, Okra, Chili, Ginger and Turmeric cultivation under solar PV modules, a comparison of the crops in two places (under solar panel and outside of the panel) was made. The Morphological characteristics regarding performance of these two places are presented in Table 5 to 12.

Table 5. Performance indicators of various crops under solar PV modules (up to 30 days)

Performance indicators	Eggplant	Okra	Chili	Ginger	Turmeric
Average height (cm)	27.5	21.25	20.25	7.5	27.5
Leaf color	Green	Green	Green	Green	Green
Plant structure	Normal	Normal	Normal	Normal	Normal
Number of plants	14	19	24	19	20
Number of dead plants	1	2	5	1	0
% of dead plant	7	11	21	5	0

Table 6. Performance indicators of various crops in open space (up to 30 days)

Performance indicators	Eggplant	Okra	Chili	Ginger	Turmeric
Average height (cm)	29	20	20.5	5	24.75
Leaf color	Green	Green	Green	Green	Light green
Plant structure	Normal	Normal	Normal	Normal	Normal
Number of plants	14	19	24	19	20
Number of dead plants	1	1	5	12	1
% of dead plant	7	5	21	63	5

Table 7. Performance indicators of various crops under solar PV modules (up to 60 days)

Performance indicators	Eggplant	Okra	Chili	Ginger	Turmeric
Average height (cm)	35	42.5	30.5	17	41.5
Leaf color	Green	Green	Green	Green	Green
Plant structure	Normal	Normal	Normal	Normal	Normal
Number of plants	14	19	24	19	20
Number of dead plants	1	5	5	1	0
% of dead plants	7	26	21	5	0
Flowering stage (days)	47	53	46	-	-
Fruiting stage (days)	51	57	49	-	-

Table 8. Performance indicators of various crops in open space (up to 60 days)

Performance indicators	Eggplant	Okra	Chili	Ginger	Turmeric
Average height (cm)	37	44.5	32	14	39.5
Leaf color	Green	Green	Green	Light green	Green
Plant structure	Normal	Normal	Normal	Undesired	Normal
Number of plants	14	19	24	19	20
Number of dead plants	1	4	5	13	1
% of dead plants	7	21	21	68	5
Flowering stage (days)	46	52	45	-	-
Fruiting stage (days)	50	53	48	-	-

Table 9. Performance indicators of various crops under solar PV modules (up to 90 days)

Performance indicators	Eggplant	Okra	Chili	Ginger	Turmeric
Average height (cm)	43	67	35.5	31.5	59.5
Leaf color	Greenish	Greenish	Green	Green	Green
Plant structure	Undesired	Undesired	Normal	Normal	Normal
Number of plants	14	19	24	19	20
Number of dead plants	11	15	18	1	0
% of dead plants	79	79	75	5	0
Production (kg)	0.5	0.10	0.05	-	-

Table 10. Performance indicators of various crops in open space (up to 90 days)

Performance indicators	Eggplant	Okra	Chili	Ginger	Turmeric
Average height (cm)	48	64.5	37	16.5	58
Leaf color	Greenish	Greenish	Green	Yellowish	Greenish
Plant structure	Normal	Undesired	Normal	Undesired	Normal
Number of plants	14	19	24	19	20
Number of dead plants	3	9	15	18	2
% of dead plants	21	47	63	95	10
Production (kg)	1.5	0.20	0.07	-	-

Table 11. Performance indicators of various crops under solar PV modules (up to 120 days)

Performance indicators	**Eggplant**	**Okra**	**Chili**	**Ginger**	**Turmeric**
Average height (cm)	47	86.36	39.37	51.34	81.6
Leaf color	Green	Green	Green	Green	Green
Plant structure	Undesired	Undesired	Normal	Normal	Normal
Number of plants	14	19	24	19	20
Number of dead plants	12	18	20	1	0
% of dead plants	86	95	83	5	0
Production (kg)	0.75	0.20	0.08	--	--

Table 12. Performance indicators of various crops in open space (up to 120 days)

Performance indicators	**Eggplant**	**Okra**	**Chili**	**Ginger**	**Turmeric**
Average height (cm)	54.9	91.44	43.45	--	78
Leaf color	Green	Green	Green	--	Greenish
Plant structure	Normal	Undesired	Normal	--	Normal
Number of plants	14	19	24	19	20
Number of dead plants	4	10	16	19	2
% of dead plants	29	53	67	100	10
Production (kg)	2.5	1	0.10	--	--

It is observed from Table 5 to 12 that the performance of Ginger and Turmeric is better under the solar PV Module than the open space. On the other hand, the performance of Eggplant and Okra is better in open space than under the solar panel. The performance of Chili greatly affected both places (Table 13).

Table 13. Overall performances of crops under solar PV module and open space

Performance under solar PV	**Crops**	**Performance in open space**
Production decreased 85%	Eggplant	Production decreased 35%
Production decreased 90%	Okra	Production decreased 55%
Production decreased 85%	Chili	Production decreased 70%
Normal growth and yield	Ginger	Production decreased 100%
Normal growth and yield	Turmeric	About normal growth and yield

2. **Comparison among the crops under solar PV Modules**

Beside comparison of crops between solar panel and open space, an attempt to see the performance of the selected five crops under solar panel has been made. Based on some indicators such as % of dead plant, growth pattern, flowering stage, fruiting stage and yield, it can be said that the performance of Turmeric and Ginger was good (Table 14).

Table 14. Performance of various crops cultivated under the solar PV modules

Crops	Performance	Comment
Egg plant	Significantly decrease yield	Loss
Okra/Ladies figure	Significantly decrease yield	Loss
Chili	Significantly decrease yield	Loss
Ginger	Close to normal growth and yield	Profitable
Turmeric	Normal growth and yield	Profitable

The government of Bangladesh spend money to import spices especially Ginger and Turmeric from various countries. The production of Ginger and turmeric under solar panel may help the government to safe foreign currency.

3. Identify the reasons behind the performance of crops under solar PV modules

Among the five cultivated crops, Eggplant, Okra and Chili failed to show normal growth and yield. The yield of these crops was very negligible. On the other hand, Ginger and Turmeric showed normal growth and yield. Even the growth and yield of Ginger under the solar PV module showed better performance than the open space. The probable reasons for decrease yield of the selected crops are soil type, temperature and shade (Table 15).

Table 15. Reasons for failure and success of selected crops beneath the solar panel

Crops with good yield	Crops with highly decrease yield	Reasons for decrease yield
Ginger	Eggplant	Soil type, temperature, shade
Turmeric	Okra	Soil type, temperature, shade
	Chili/Green pepper	Soil type, temperature, shade

a. Soil status

The soil of the experimental field is sandy with very low organic carbon and macro and micronutrients. The amount of organic carbon in the experimental site soil is 0.2% where it is 1.5% to 2% in the nearby agriculture land and 5% in standard level (Figure 1). The acceptance of other nutrients (N, P, K) by soil gain from fertilizer also relates with the level of organic matter. If the organic matter is low in the soil, then other nutrients uptake capacity also becomes low. Moreover, water holding capacity of sandy soil is very poor. These features negatively affect the growth and development of the crops.

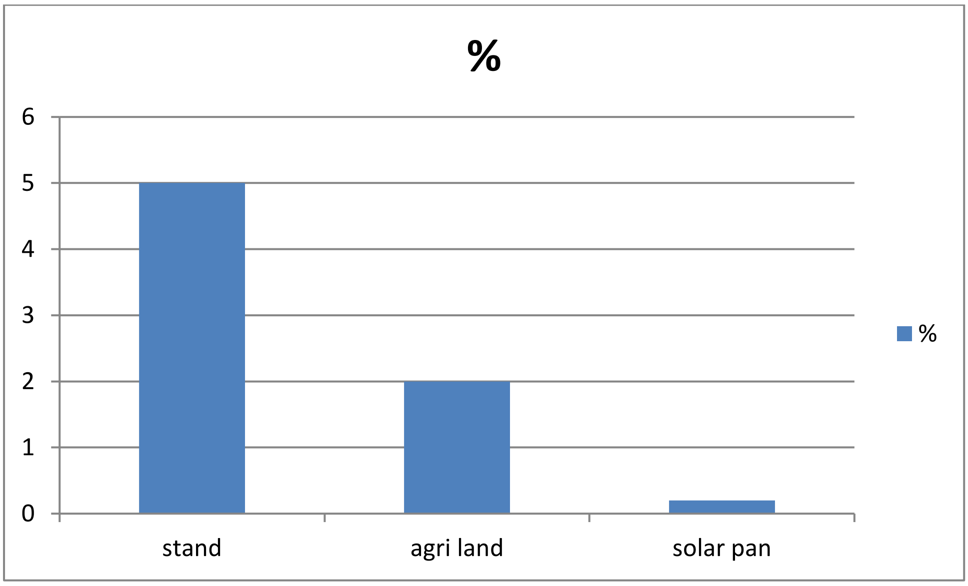

Fig 1. Organic matter in soil (experimental field, nearby agricultural land and standard land)

b. Temperature

The study period was from July to November 2024. The average temperature was 32^{0}C in the study period and place. Few days of September 2024 (mid-September) showed extreme heat (37^{0}C). The sandy soil heated quickly with high temperature. On the other hand, the solar panel also consumes heat which has an effect on the soil.

c. Shade

It is assumed that growth and development of Eggplant, Okra and Chili under the solar panel was affected by shade. This is because these crops have shown better performance in the open space.

Recommendations

- The yield of Turmeric and Ginger is higher beneath the solar PV module than the open space. Therefore, these spices are ideal crops to cultivate under solar PV module.

- As the soil is sandy, therefore, experiment can be carried out with crops suitable for sandy soil like groundnut, watermelon and muskmelon. These crops have high demand in the market also.

- The experiment was carried out with a few summer crops. A further experiment should be carried out with winter crops.

- The spectra solar park authority should take initiative to increase soil organic carbon through applying organic manure.

k. Way forward

- More experimental trials with a variety of crops should be conducted
- Stakeholders meeting with expertise on agri-PV (including foreign country especially from India) to fine tune the approach is necessary
- The government should encourage and provide incentives and awards for establishing agri-pv
- Research on the key stakeholder's social acceptance of agri-PV should be conducted

4. Issues and Limitations

a. Technical

Spectra has installed a 35 MW solar park in Manikganj covering 140 acres of area to supply electricity to the national grid. The height of the Panel is 2 meters, thus crops higher than two meters height cannot be cultivated. The orientation of the panel is not suitable to entry enough light to the crops.

b. Economic

The experiment was conducted with a small grant and brief period. Due to limited resources, it covered only 2 decimals of land and five distinct types of summer crops. The study period was 5 months among which 4 were active months for crop cultivation.

C. Environmental

The Spectra Solar Park is situated at the bank of Padma River. The authority increases the height of the structure through sandy soil. Sandy soil with low organic carbon and low macro and micronutrients make difficult to produce crops. The annual average temperatures reach a maximum of 36 °C and a minimum to 12.7 °C.

d. Social / Public Acceptance

The Agri-PV approach can help to achieve power and food security both. In a country like Bangladesh where population is increasing, agricultural land is decreasing; such an approach should welcome by the stakeholders and community. However, failure to reach desired crop yield may raise question regarding public acceptance. There is a lack of research on key stakeholders (farmers) willingness to implement Agri-PV technology.

e. Awareness

The Agri-PV is a new approach for the people of Bangladesh. There is a lack of awareness among the stakeholders about the success of this approach. The public and private sectors initiative to establish more Agri-PV may help to increase awareness among the people about this technology.

5. Best practices

a. international case studies

i. India
ii. Germany

i) India

There are several solar plants in India where agricultural practices are followed. Out of those plants, some have shown good performance regarding crop cultivation. A list of findings regarding best practice from the case studies of India is shown in Table 16.

Table 16. Best Agri-PV practices in India

Name of project	Agricultural practice
Sunmaster agrivoltaics plant, Delhi	Eggplant, lettuce, spinach, lady finger, potatoes, tomatoes, bottle gourd, fenugreek, coriander and cucumber
Sunseed apv agrivoltaics plant, Maharashtra	Potato, watermelon, spinach and lettuce
Indra solar farm, agrivoltaics plant, Madhya Pradesh	Wheat, green gram, maize and turmeric
Central arid-zone research institute (cazri), agrivoltaics plant, Rajasthan	Mungbean, moth bean, clusterbean, isabgol, cumin, chickpea, aloe vera, sonamukhi, sankhpuspi, chili, cabbage, onion, and garlic.
Agrivoltaics plant at Telangana agricultural university, Telangana	Amaranthus, palak, green gram, and black gram

Source: (Solar Power Europe, 2024- India edition)

ii) Germany

Germany is one of the leading countries regarding introduce and implementation of Agri-PV approach. Some of the best practices in Germany regarding Agri-PV approach are shown in Table 17.

Table 17. Best Agri-PV practices in Germany

Name of project/research location	Agricultural practice
APV RESOLA Project	Potato, Celery and winter wheat
Fraunhofer Institute for Solar Energy Systems ISE	Apple and berry crops
German Solar Research Institute	Pome and soft fruit
The Weihenstephan-Triesdorf University of Applied Sciences	Potato and lettuce
Agrivoltaic system on organic soft fruit farm in Büren	Blueberry and Strawberry

Source: (Czyżak and Mindeková, 2024; Bhambhani, 2024; Trommsdorff et al., 2024)

iii) Other Countries

Except to India and Germany, there are some countries like China, Japan, USA, French, Italy, the Netherlands, Poland, Slovakia, Greece, Spain, Chile, Honduras, Mali, Israel, Hungary etc. implemented Agri-PV approach. Findings regarding best practices from the case of Greece, Spain and Italy are shown in the Table 18.

Table 18. Best Agri-PV practices in Greece, Spain and Italy

Country	Name of project	Agriculture practice
Greece	Pezouliotika PV plant, located in Thrace.	Cultivation of aromatic herbs, flowers and mixes of plants capable of attracting pollinating species.
	Kourtesi PV plant, located in Ilia region.	Cultivation of medicinal herbs, cardoon and safflower.
Spain	Totana PV plant, located in Murcia region.	Cultivation of artichokes, broccoli, peppers, pitaya, medicinal and aromatic herbs.
	Valdecaballeros PV plant located in Extremadura region	Cultivation of medicinal and aromatic herbs
	Augusto PV plant, located in Extremadura region	Cultivation of forage crops, broccoli, eggplants, cauliflower.
	Las Corchas PV plant located in Andalusia	Cultivation of lavender and flowers attract pollinators.
Italy	Bastardo PV plant, located in Umbria	Cultivation of different species of herbs and forage crops, cucurbits and combinations of plants that attract pollinators.
	Montalto di Castro PV plant, located in Latium	Cultivation of legumes, asparagus and saffron.

Source: (Solar Power Europe, 2021)

b. Agri-PV in Bangladesh

v. Pilot if any

Among the solar plants of Bangladesh, some are doing pilot test whereas others have plan to implement Agri-PV approach. An outline of the pilot test is shown in the Table 19.

Table 19. Pilot project of crop cultivation under Solar PV modules in Bangladesh

Project name	Year of commissioning	Year of pilot experiment	Crops for Pilot experiment
Spectra 35 MW Solar Park Limited, Manikganj	2021	2024	Eggplant, Okra, Chili, Ginger and Turmeric
Sirajganj 6.55MW Grid Connected Solar Photovoltaic Power Plant	2021	2023	Cucumber, Pumpkin and Spinach
Lalmonirhat 30 MW Solar Power Plant	2022	2024	Turmeric, Ginger, Pumpkin, Taro, Napier grass

Source: (Raana, 2023; Anonymous, 2024; Islam, 2022).

vi. Research studies or activities

Shafiullah et al., (2024) conducted a study on Agrivoltaics system for sustainable agriculture and green energy in Bangladesh and proposed a new agrivoltaics system that achieves full land utilization, by producing crops along with electricity generation with the lowest payback period, highest profit margin, and highest benefit-cost ratio over the project lifetime.

Another study conducted by Shams et al., (2022) on Assessing the Efficiency of a Proposed Agrivoltaic System in Bangladesh to Ensure Multiple Uses of Land and Water. The study found that agri-PV can provide environmental and economic sustainability by producing clean energy and conserving water.

vii. Stakeholders involved in

At the moment the private companies, developer or entrepreneurs are establishing solar project with an aim to only produce energy/power. On the other hand, government is implementing a number of solar pump irrigation by set up solar panel in the crop field with an aim to only provide irrigation in the crop field. In both cases, there have possibility to adopt agri-PV approach through involvement of farmers, agriculturist, experts and donor organizations.

6. Policy aspects

a. Status quo

The government of Bangladesh welcome renewable energy sources to produce energy to meet country requirement. The objectives of renewable energy policy of Bangladesh are to harness the potential of renewable energy resources and dissemination of renewable energy technologies in rural, peri-urban and urban areas; to enable, encourage and facilitate both public and private sector investment in renewable energy projects. As a result, the number of Solar Plants is increasing day by day in Bangladesh. However, majority of them produce power only thus there is a lack of Agri-PV program.

b. Recommendations

More Agri-PV technology should be established through the combine effort of public and private sectors. The responsible authority of the government should collaborate with the donor organizations for research funding on the prospect and problem of Agri-PV in Bangladesh.

7. Specific situation in Bangladesh

a. Status quo

Agri-PV is a new approach for Bangladesh. The Soudia Agro Solar PV Power Plant Ltd is considered as first Agri-PV project in Bangladesh. It is situated in Pabna district and is in development stage. The WAVE foundation established an Agri-PV in Damurhuda upazila under Chuadanga district and has recently started production.

b. Next steps for BD

At the moment the number of Agri-PV projects in Bangladesh is very few. Majority of the Solar Park Project established to produce only power. These projects should move towards Agri-PV approach. Besides, more Agri-PV project should be launched. On the other hand, research on social acceptance and economic and environmental aspect of agri-PV should be conducted to develop efficient business model.

8. Synergies

a. Combination with other energy generating systems

Bangladesh produces less than 1% of its electricity from hydro and less than 1% from solar and wind. Experiment should be carried out on how to make a combination with Solar Panel to other energy generating system like hydro-energy and wind-energy to produce electricity and food.

9. Prospects

Agri-PV is a rapidly expanding sector with incredible potential. It brings together two major sectors of our society and economy: agriculture and energy. In Bangladesh, where agricultural land is gradually decreasing and ensuring food security is challenging, there is an ample scope to get advantages from Agri-PV. This technology enables us to move away from the traditional land-use competition towards a new paradigm based on synergies between agriculture and renewable energy. The farmers may improve their livelihood through involvement with Agri-PV. Moreover, the approach can boost sustainable rural development and can increase biodiversity protection.

References

Adeh, E.H.; Selker, J.S.; Higgins, C.W. Remarkable Agrivoltaic Influence on Soil Moisture, Micrometeorology and Water-Use Efficiency. PLoS ONE 2018, 13, e0203256.

Annonymous, (2024). A report on Veg farming now beneath solar panels. Published at Bangladesh Post on 1 June 2024.

Boruah, M. D., Das, M. P., & Priyadarshi, M. A. (2023). Setting up of Optimum Design Parameters for Agrivoltaic Power Plants in Indian Geo-Climatic Conditions.

Bhambhani, A. 2024. A Newsletter on Fraunhofer ISE Releases Interim Results for Agrivoltaic Research.

Campbell, B.M.; Thornton, P.; Zougmoré, R.; van Asten, P.; Lipper, L. Sustainable Intensification: What Is Its Role in Climate Smart Agriculture? Curr. Opin. Environ. Sustain. 2014, 8, 39–43.

Czyżak, P and Mindeková, T. 2024. Empowering farmers in Central Europe: the case for agri-PV.

Harsha, J. Micro Irrigation in India: An Assessment of Bottlenecks and Realities. 2017. Available online: http://www. globalwaterforum.org/2017/06/13/micro-irrigation-in- india-an-assessment-ofbottlenecks-and-realities (accessed on 31 July 2021).

Islam, S. (2022). A report on Bangladesh switches on 30 MW of solar at PV Magazine dated September 1, 2022.

Jain, R.; Kishore, P.; Singh, D.K. Irrigation in India: Status, Challenges and Options. J. Soil Water Conserv. 2019, 18, 354.

Krishnan, G., Molleti, G., Banerjee, B. and Ghosh, S. 2023. Exploring Business Models for in India Karnataka: A Case Study. Center for Study of Science, Technology and Policy, Bengaluru and Noida.

Lal, R. Integrating Animal Husbandry with Crops and Trees. Front. Sustain. Food Syst. 2020, 4, 113.

Lipper, L.; Thornton, P.; Campbell, B.M.; Baedeker, T.; Braimoh, A.; Bwalya, M.; Caron, P.; Cattaneo, A.; Garrity, D.; Henry, K. Climate-Smart Agriculture for Food Security. Nat. Clim. Chang. 2014, 4, 1068–1072.

Mahto, R.; Sharma, D.; John, R.; Putcha, C. Agrivoltaics: A Climate-Smart Agriculture Approach for Indian Farmers. Land 2021, 10, 1277.

Marrou, H.; Dufour, L.; Wery, J. How Does a Shelter of Solar Panels Influence Water Flows in a Soil—Crop System? Eur. J. Agron. 2013, 50, 38–51

Patel, U. R., Gadhiya, G. A., & Chauhan, P. M. (2023). Case study on power generation from agrivoltaic system in India. *Int. J. Environ. Clim. Chang*, *13*, 1447-1454.

Rahman, A. Sharma, A. Postel, F. Goel, S. Kumar, K. and Laan, T. 2023. IISD Report on Agrivoltaics in India: Challenges and opportunities for scale-up.

Schindele, M. Trommsdorff, A. Schlaak, T. Obergfell, G. Bopp, C. Reise, C. Braun, A. Weselek, A. Bauerle, P. Högy, A. Goetzberger, and E. Weber: Implementation of agrophotovoltaics: Techno-economic analysis of the price-performance ratio and its policy implications. Applied Energy 265 (2020), p. 114737.

Solar Power Europe (2021): Agrisolar Best Practices Guidelines Version 1.0

STEAG, (2023). A report on Feasibility study for multipurpose use of land for renewable energy project in Bangladesh by STEAG Energy Services India Pvt. Ltd.

Sharma, N.; Singhvi, R. Effects of Chemical Fertilizers and Pesticides on Human Health and Environment: A Review. Int. J. Agric. Environ. Biotechnol. 2017, 10, 675–680.

Shafiullah, G. M., Ferdous, S. M., Shoeb, M., Reza, S. S., Elavarasan, R. M., & Rahman, M. M. (2024). Agrivoltaics system for sustainable agriculture and green energy in Bangladesh. *Applied Energy*, *371*, 123709.

Shams, S. N., Mojumder, T. H., Khan, M. F. H., & Shuvo, K. H. (2022). Assessing the Efficiency of a Proposed Agrivoltaic System in Bangladesh to Ensure Multiple Uses of Land and Water. *The Dhaka University Journal of Earth and Environmental Sciences*, *11*(2), 33-41.

Solar Power Europe (2024): Agrisolar Best Practices Guidelines India Edition.

Toledo, C.; Scognamiglio, A. Agrivoltaic Systems Design and Assessment: A Critical Review, and a Descriptive Model towards a Sustainable Landscape Vision (Three-Dimensional Agrivoltaic Patterns). Sustainability 2021, 13, 6871

Trommsdorff, M., Gruber, S., Keinath, T., Hopf, M., Hermann, C., Schönberger, F., Gudat, C., Boggio, A. T., Gajewski, M., Högy, P., Zikeli, S., Ehmann, A., Weselek, A., Bodmer, U., Rösch, C., Ketzer, D., Weinberger, N., Schindele, S., and Vollprecht, J. 2024. Agrivoltaics: Opportunities for Agriculture and the Energy Transition, A Guideline for Germany | February 2024. Published by Fraunhofer Institute for Solar Energy Systems ISE Heidenhofstrasse 2 79110 Freiburg, Germany.

Weselek, A.; Ehmann, A.; Zikeli, S.; Lewandowski, I.; Schindele, S.; Högy, P. Agrophotovoltaic Systems: Applications, Challenges, and Opportunities. Rev. Agron. Sustain. Dev. 2019, 39, 35.

Appendix

Plate 1: Land preparation

Plate 2. Eggplant at the age of 30 days in open space

Plate 3. Eggplant at the age of 30 days under the solar PV

Plate 4. Turmeric in the age of 30 days under the solar PV

Plate 5. Turmeric at the age of 30 days in open space

Plate 6. Okra/lady finger at the age of 30 days under solar PV

Plate 7. Okra at the age of 30 days in the open space

Plate 8. Eggplant under the solar panel in the age of 60 days

Plate 9. Eggplant in open space at the age of 60 day

Plate 10. Okra in the age of 90 days in the open space

Plate 11. Okra in the age of 90 days under the solar PV

Plate 12. Chili/Green pepper at the age of 60 days in the open space

Plate 13. Chili in the age of 90 days under the solar PV

Plate 14. Eggplant in the age of 120 days under the solar PV

Plate 15. Ginger at the age of 120 days under the solar PV

Plate 16. Eggplant in the age of 120 days in the open space

Plate 17. Turmeric in the age of 120 days under the solar PV

Plate 18. Ginger at the age of 120 days under the solar PV