Agri-voltaic system

Experiences with water harvesting systems

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India Expo Center, Greater Noida
Shamrock Hall, 2nd Floor

Session II: AgroPhotovoltaics – Harvesting the Sun for Power and Food

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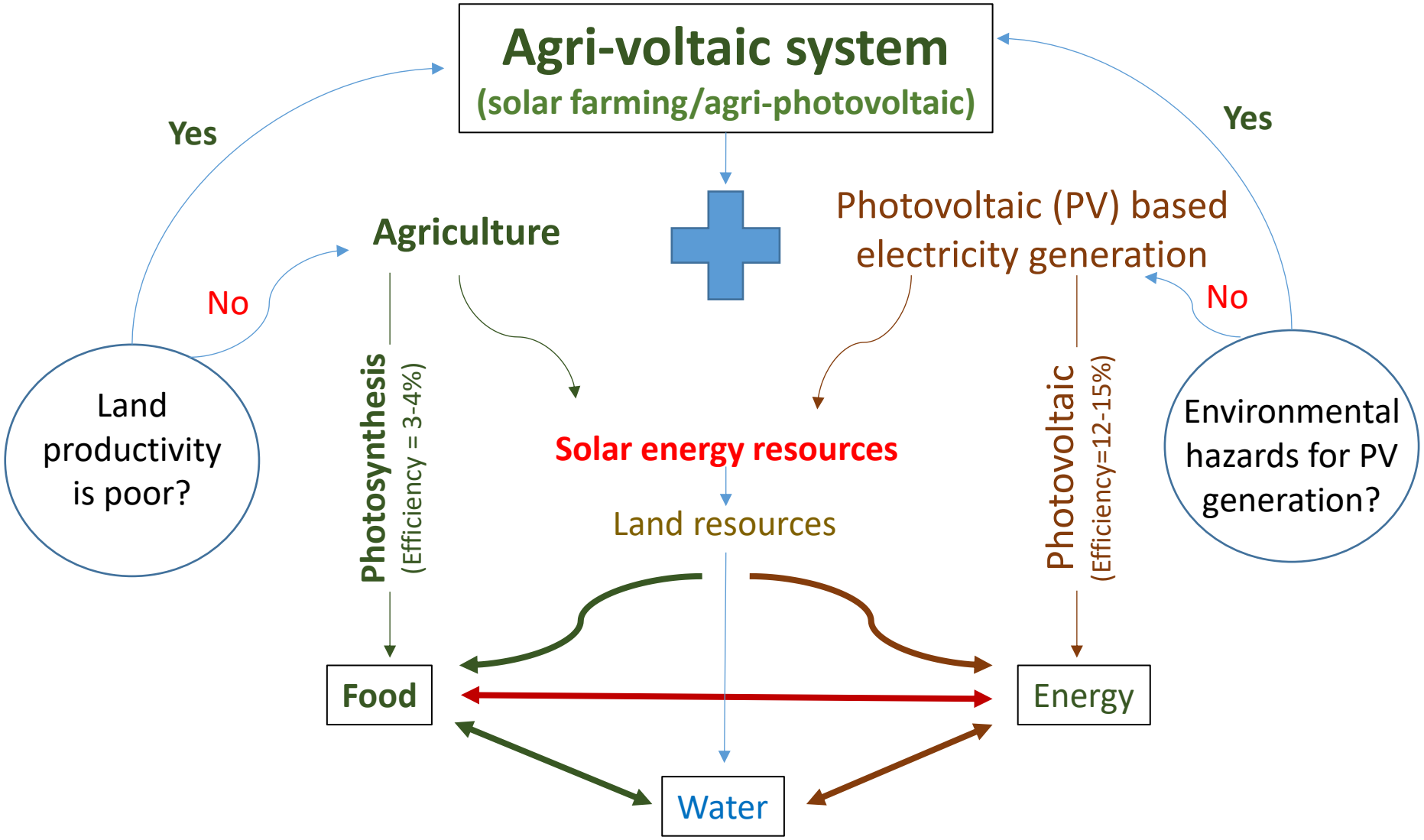
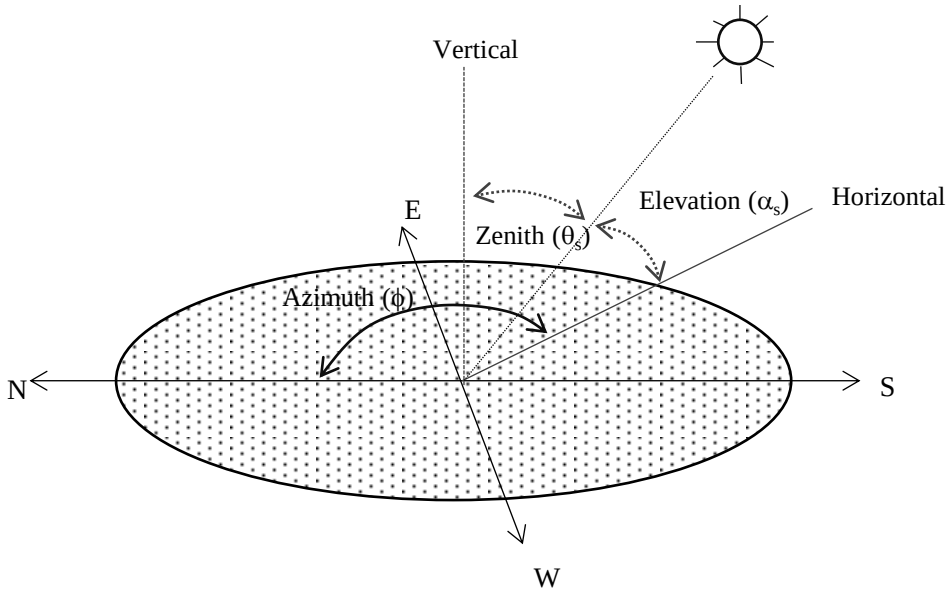

Agri-voltaic system
(solar farming/agri-photovoltaic)
Yes
Yes
Agriculture
Photovoltaic (PV) based electricity generation
No
No
Land productivity is poor?
Environmental hazards for PV generation?
Photosynthesis
(Efficiency = 3-4%)
Photovoltaic
(Efficiency=12-15%)
Solar energy resources
Land resources
Food
Energy
Water

Design criteria of agri-voltaic system



$$\cos\theta_s = \sin\varphi \sin\delta + \cos\varphi \cos\delta \cos h$$

$$\cos\emptyset_s = \frac{\sin\delta \cos\varphi - \cos\delta \sin\varphi \cos h}{\cos\theta_s}$$

$$\delta = 23.45 \sin(B)$$

$$B = \frac{360}{365}(d - 81)$$

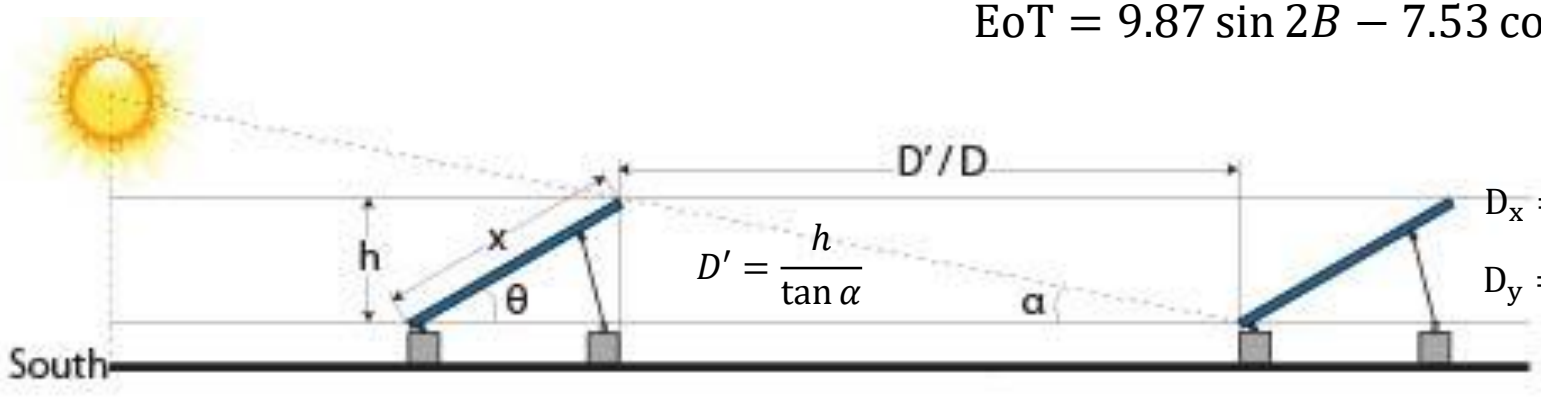
$$h = 15(\text{LST} - 12)$$

$$\text{LST} = \text{LT} + \frac{\text{TC}}{60}$$

$$\text{TC} = 4(\text{Longitude} - \text{LSTM}) + \text{EoT}$$

$$\text{LSTM} = 15\ \Delta\text{GMT}$$

$$\text{EoT} = 9.87 \sin 2B - 7.53 \cos B - 1.5 \sin B$$



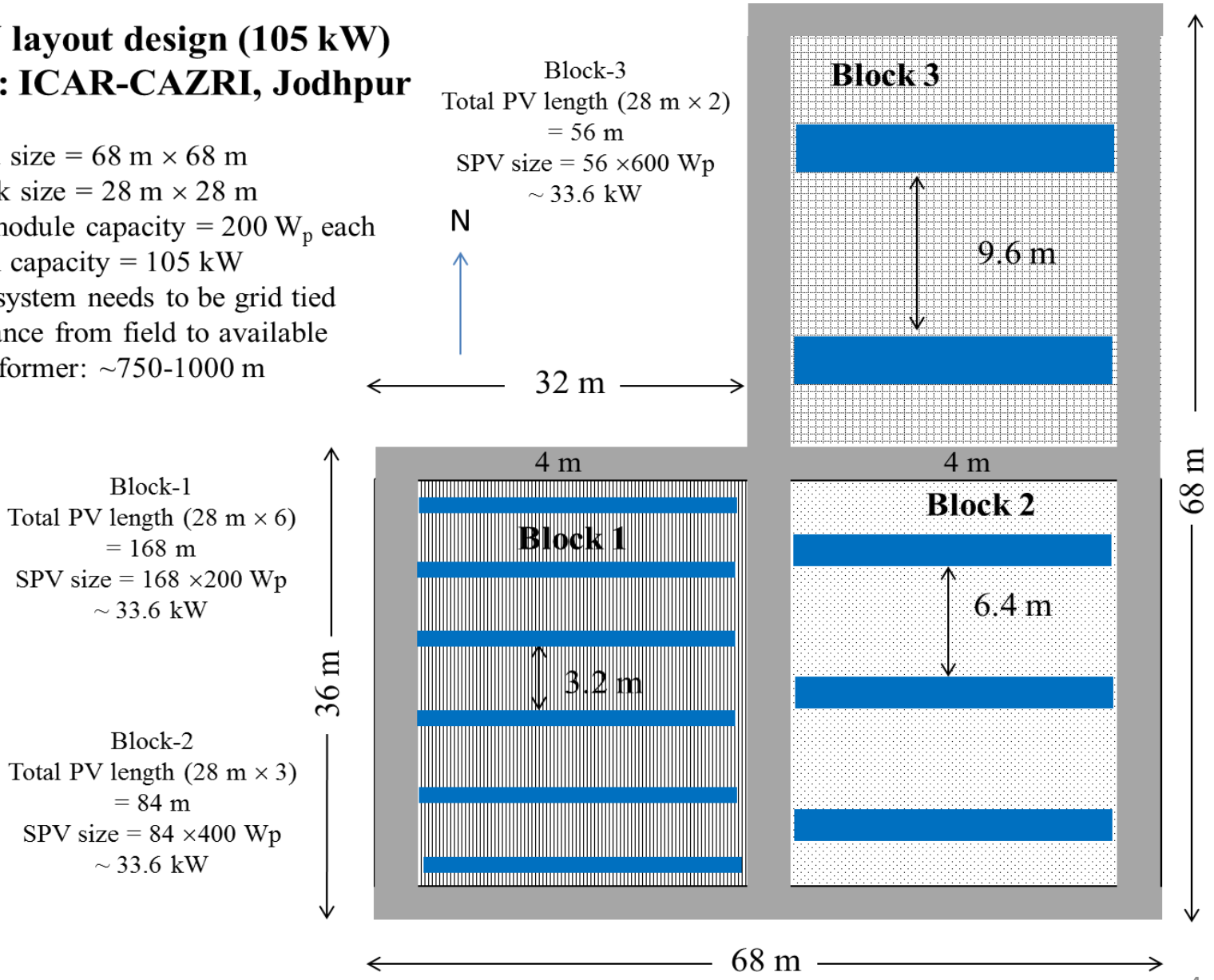
$$D' = \frac{h}{\tan\alpha}$$

$$D_x = D' \sin\ (180 - \emptyset)$$

$$D_y = D' \cos\ (180 - \emptyset)$$

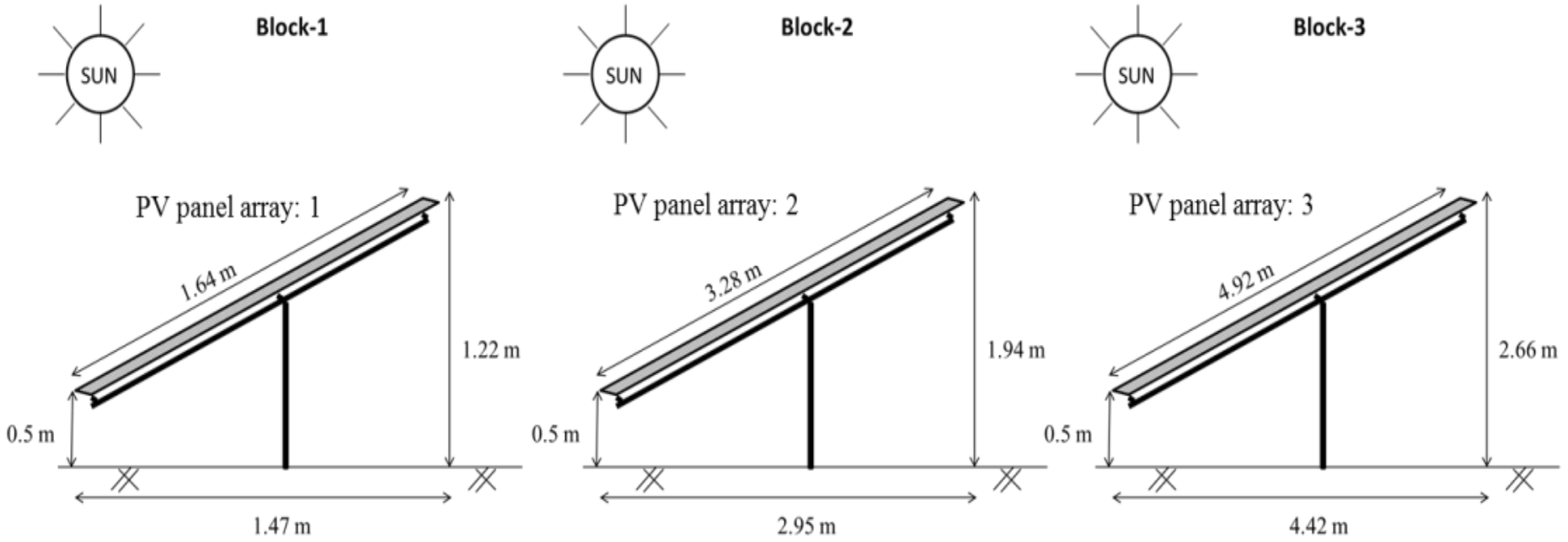
SPV layout design (105 kW)
Place: ICAR-CAZRI, Jodhpur

- Field size = 68 m × 68 m
- Block size = 28 m × 28 m
- PV module capacity = 200 W_p each
- Total capacity = 105 kW
- The system needs to be grid tied
- Distance from field to available transformer: ~750-1000 m



PV module installation design

Inclination of the PV module = 26° (latitude of Jodhpur)



Interspace area and below panel area is used for crop cultivation
Interspace area = 49% of the total installation area
Below panel area = 24% of the total installation area

Performance of crops in agri-voltaic system at Jodhpur

Kharif crops: Growth and yield of *Vigna radiata* was not affected by the shade of PV module, whereas rest two are affected

Rabi crops: Growth and yield of *Plantago ovata* and *Cuminum cyminum* are significantly affected by shade of PV module

Medicinal crops: Performance of medicinal crops were superior in the interspace area than over control

Vegetable crops: Growth and yield of Solanum melongena was significantly affected by shade of PV module

Rainwater harvesting in agri-voltaic system

Rainfall

Annual rainfall in Jodhpur 350 mm

Top of PV module

260 W_p PV module 1.64 m × 0.992 m

Water conveying MS sheet channel

Rectangular shape 2° slope

Underground PVC pipe network

6 inch dia 2 ft below depth

Water storage tank

1 lakh litre capacity

Solar PV pump

Efficiency of the system is 69.2%.

Cleaning of PV module

Supplemental irrigation

Field photographs of rainwater harvesting system

Field photographs of agri-voltaic system at ICAR-CAZRI, Jodhpur

Field photographs of agri-voltaic system at ICAR-CAZRI, Jodhpur

Field photographs of agri-voltaic system at ICAR-CAZRI, Jodhpur

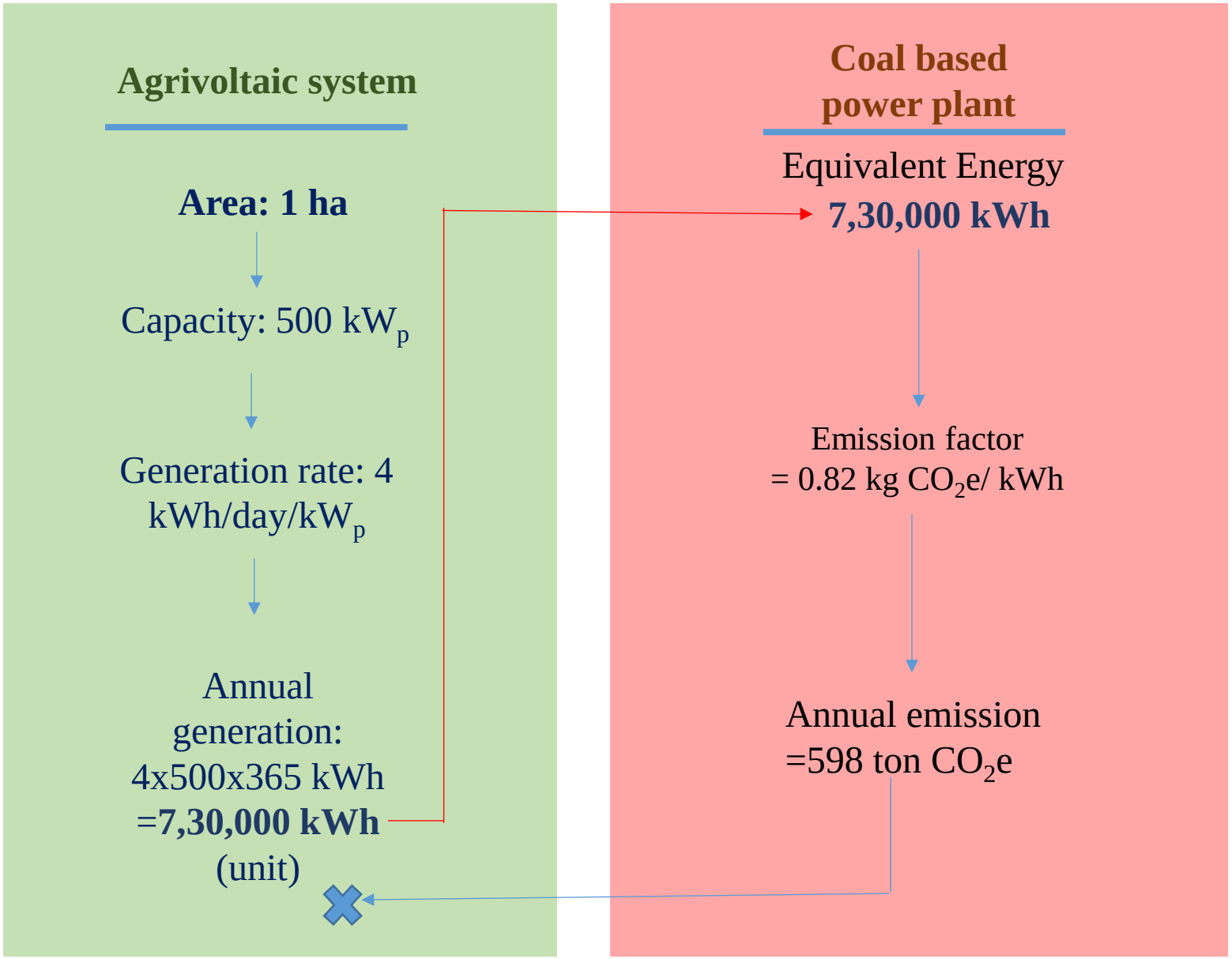
Economics and Land Equivalent Ratio

Sr. No.	Item	Value
1.	Area	1 ha
2.	Capacity	500 kW_p
3.	Life cycle	25 years
4.	Capital investment	Rs 2,25,00,000/-
5.	Replacement cost for inverter	Rs 30,00,000/-
6.	Mainteance cost @0.5%	Rs 1,12,500/-
7.	Annual generation (@4 kWh/day/kWp)	7,30,000 kWh
8.	Electricity sale price	Rs 4.00/-
9.	Cash inflow per year (Electricity)	Rs 23,28,700/-
10.	Cash inflow per year (Crop)	Rs 80,000/-
11.	Simple payback period	6.65 years
12.	Discounted payback period	12.94 years
13.	Internal rate of return	13%
14.	Net present value at a discount rate of 10%	Rs 60,02,815

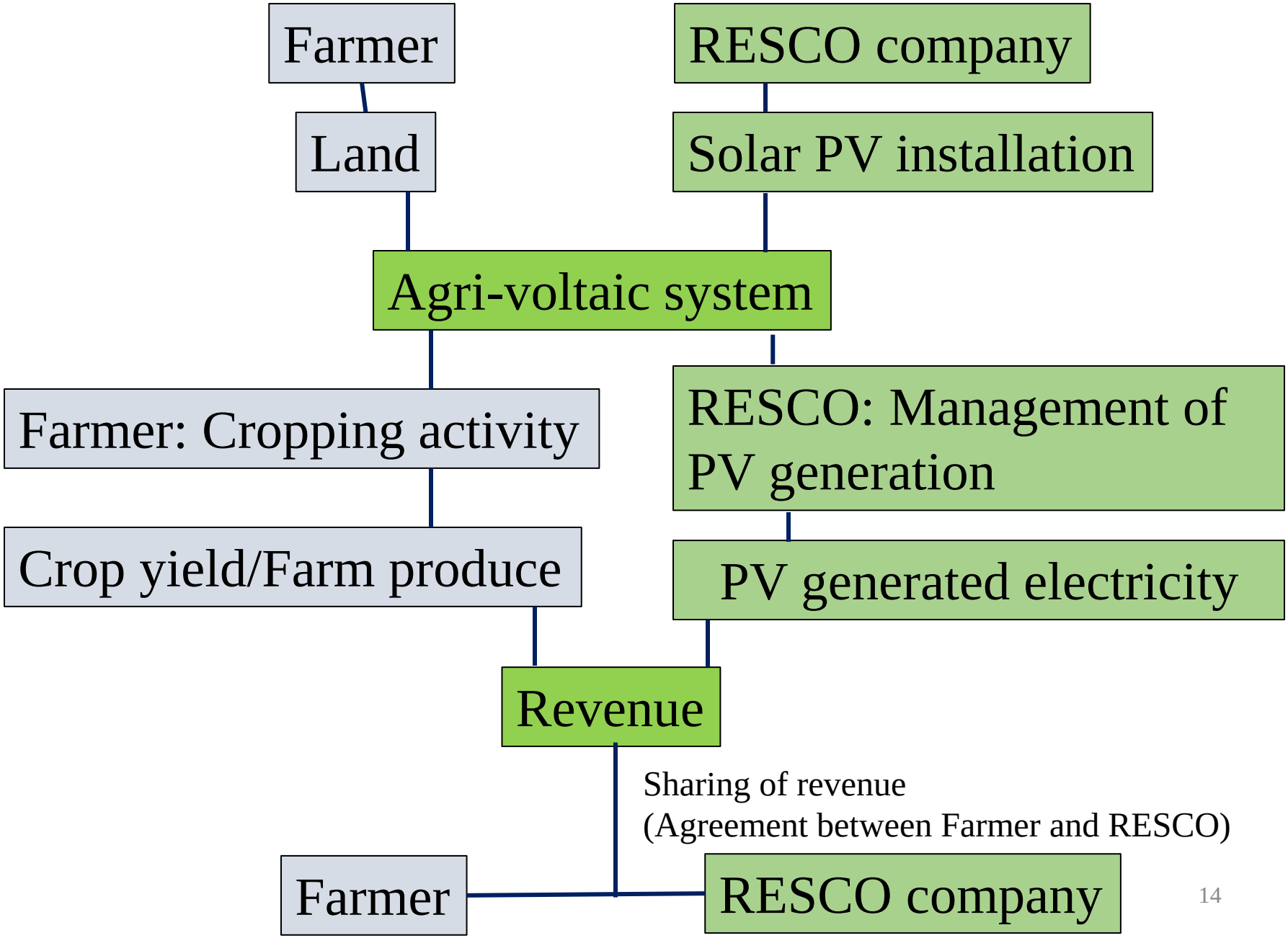
$$\text{LER} = \frac{\text{Electricity generation}_{\text{Agri-voltaics}}}{\text{Electricity generation}_{\text{Sole}}} + \frac{\text{Crop yield}_{\text{Agri-voltaics}}}{\text{Crop yield}_{\text{Sole}}}$$

LER value of 1.41 can be achieve

Green energy generation



Agri-voltaic system in Farmer's field-Proposed for KUSUM scheme



Benefits of Agri-voltaic system

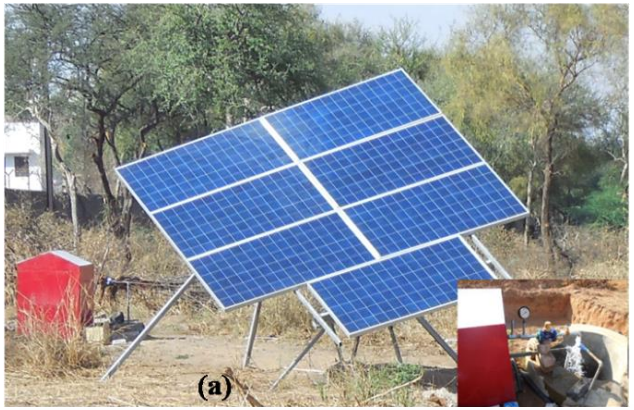
- Increased income from farm land
- Recycling of harvested rainwater for cleaning PV modules and irrigating crops (1.5 lakh litre per acre and can provide 40 mm irrigation in 1 acre land)
- Improvement in microclimate for crop cultivation and optimum PV generation
- Reduction in soil erosion by wind
- Reduction in dust load on PV panel
- Improvement in land equivalent ratio (LER ~1.41)
- Soil moisture conservation by reducing the wind speed on ground surface
- Reduction in GHG emission (598.6 tons of CO_2 savings/year/ha)

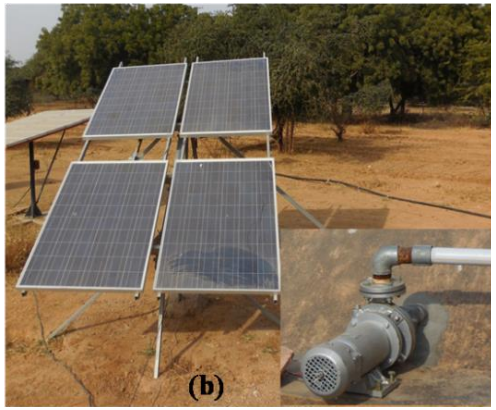
Few perceived drawbacks

- Safety of field workers engaged in agricultural activity
- Managerial complexity: additional load on plant manager for agricultural activity
- Ownership issue: Farmer and solar power plant functionary
- Sharing of benefits in case of joint venture
- High capital investment during initial establishment

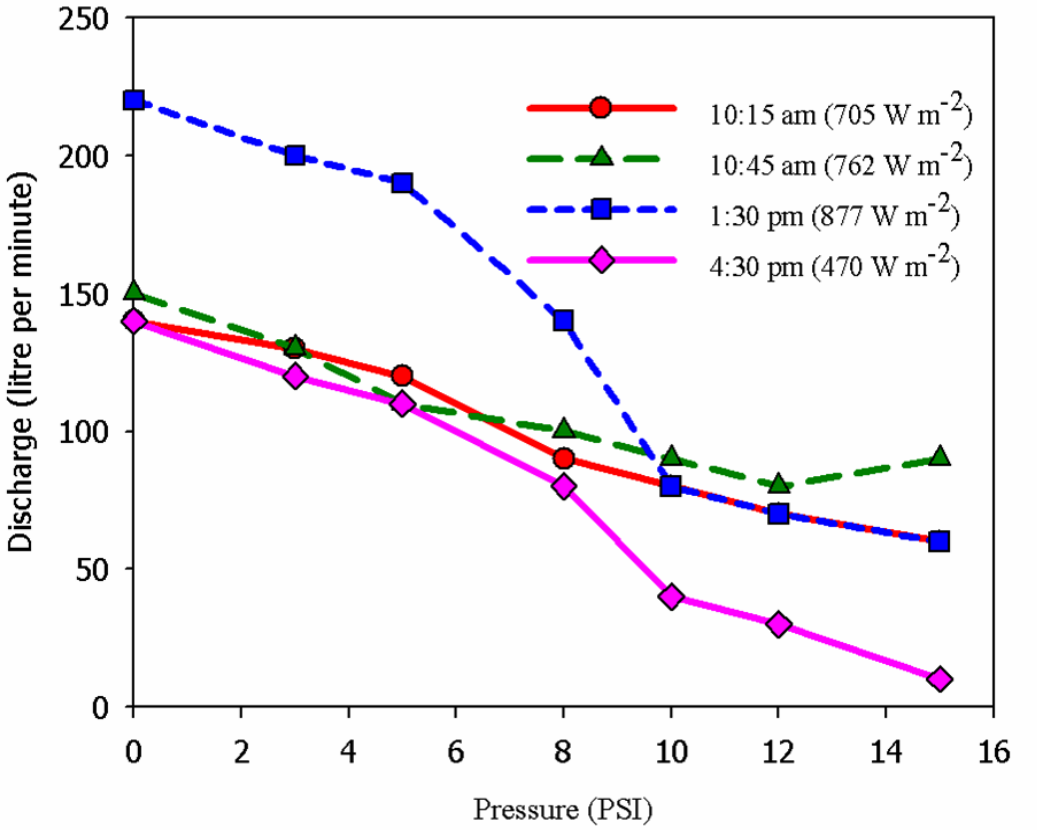
Pressure-discharge relationship of solar PV pump

1 HP PV Pump

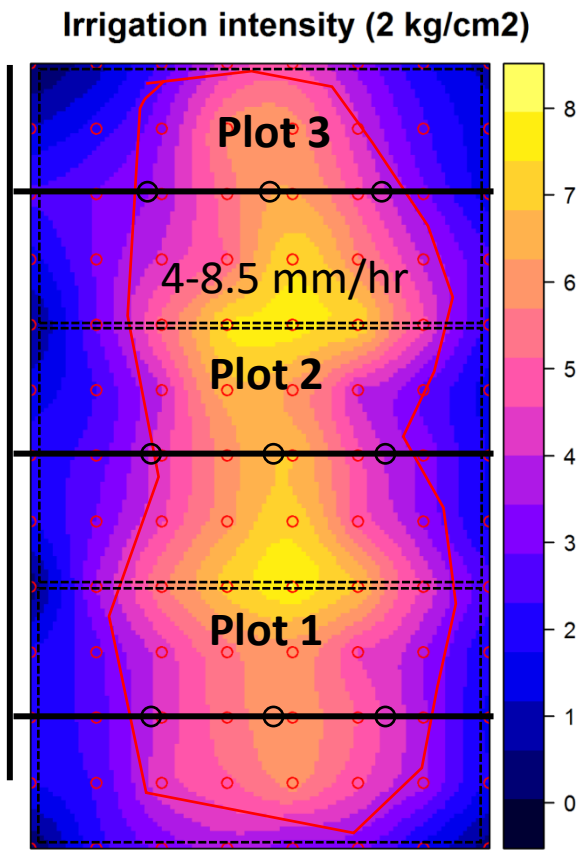


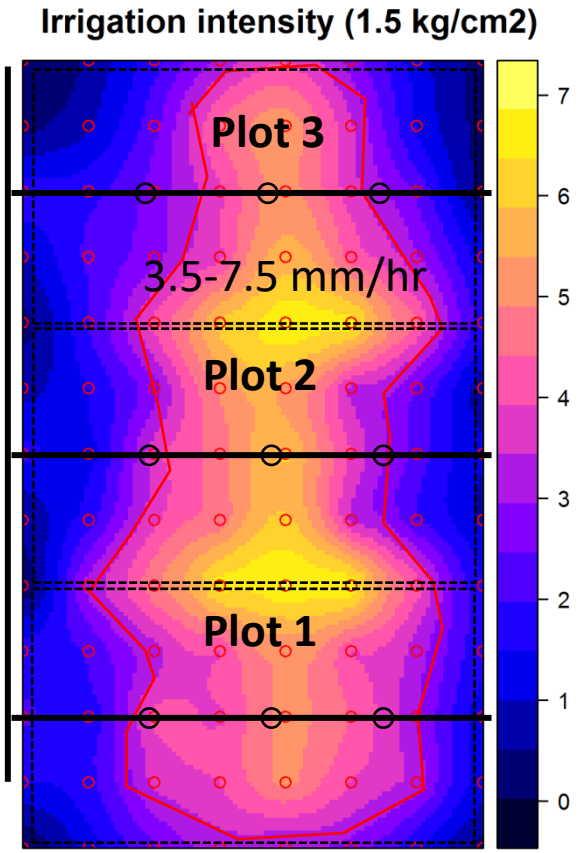


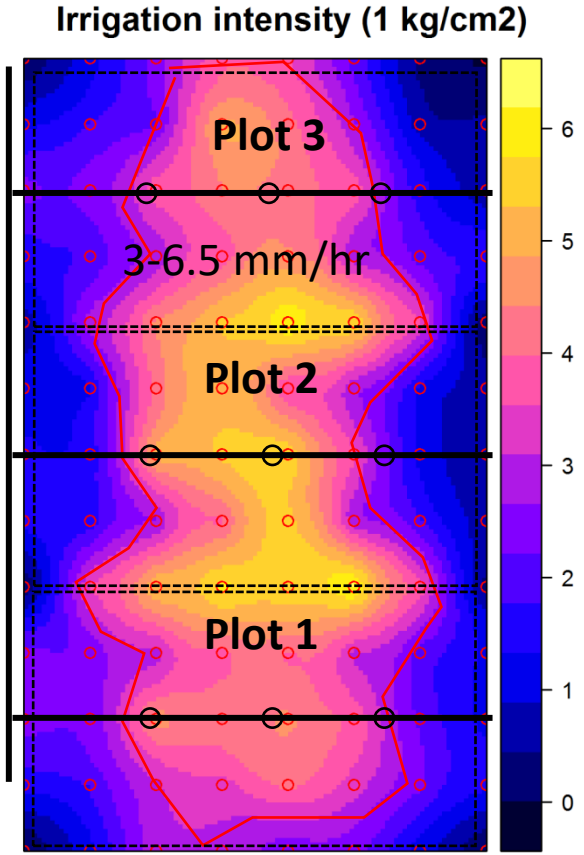
Pressure-discharge
At different solar
irradition



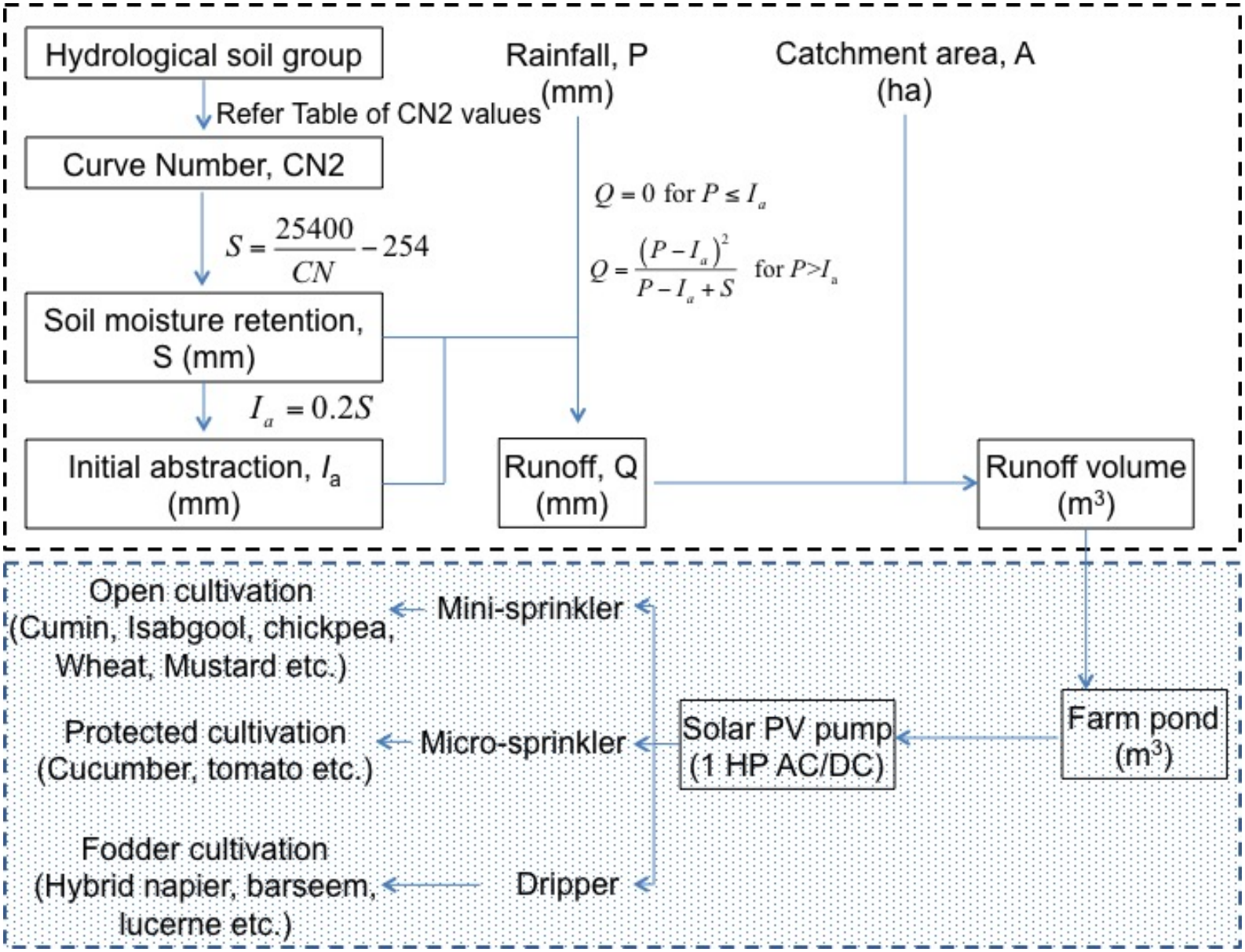
Irrigation intensity under solar PV Pumping system







Module for solar PV pump based irrigation from harvested rainwater in farm pond



Solar PV pump and farm pond

Capacity: 32,00,000 litre
Funding agency: ICARDA, Syria

Capacity: 1,70,000 litre
Funding agency: NABARD

Performance of mini-sprinklers operated by 1 HP AC pump

Performance of micro-sprinklers operated by 1 HP DC pump


Thank you
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