Agrovoltaic systems for crop improvement in Equatorial Andean Regions

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1. Introduction

The current study evaluates the deployment of a grid-independent agrovoltaic system for maximizing land utilization and crop productivity. An integrated irrigation and monitoring system powered by solar energy is incorporated to enhance crop growth.

The annual global horizontal insolation in Ecuador ranges from 2.8 to 6.5 kWh/m²day. Being closer to the equator at 2500 meters above sea level produces high solar irradiation levels, providing a good potential to implement solar energy technology.

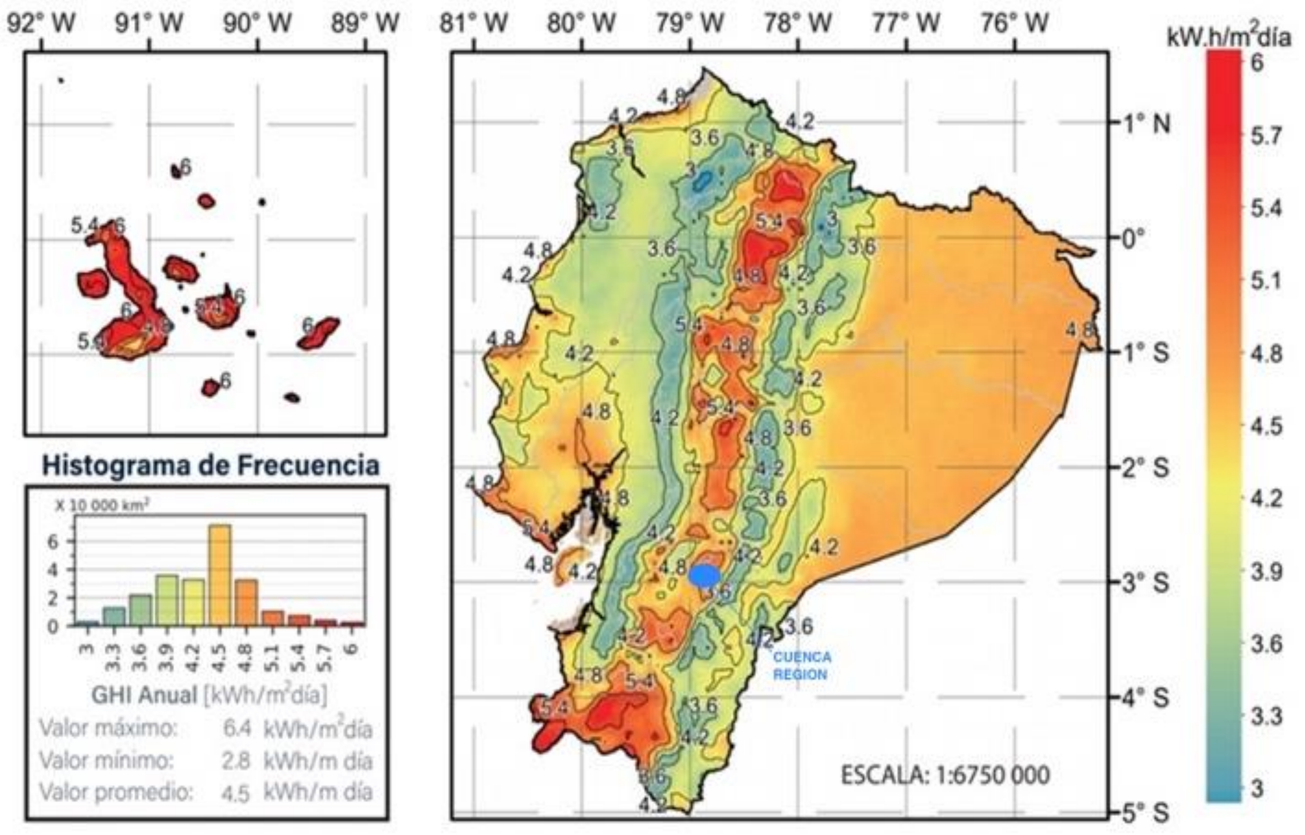

Fig. 1. Annual Global Horizontal Solar Irradiance [15]

2. Sizing of the agrovoltaic system

The experimental system includes an area of 20 m2 for the lettuce crop, as shown in Figure 2.

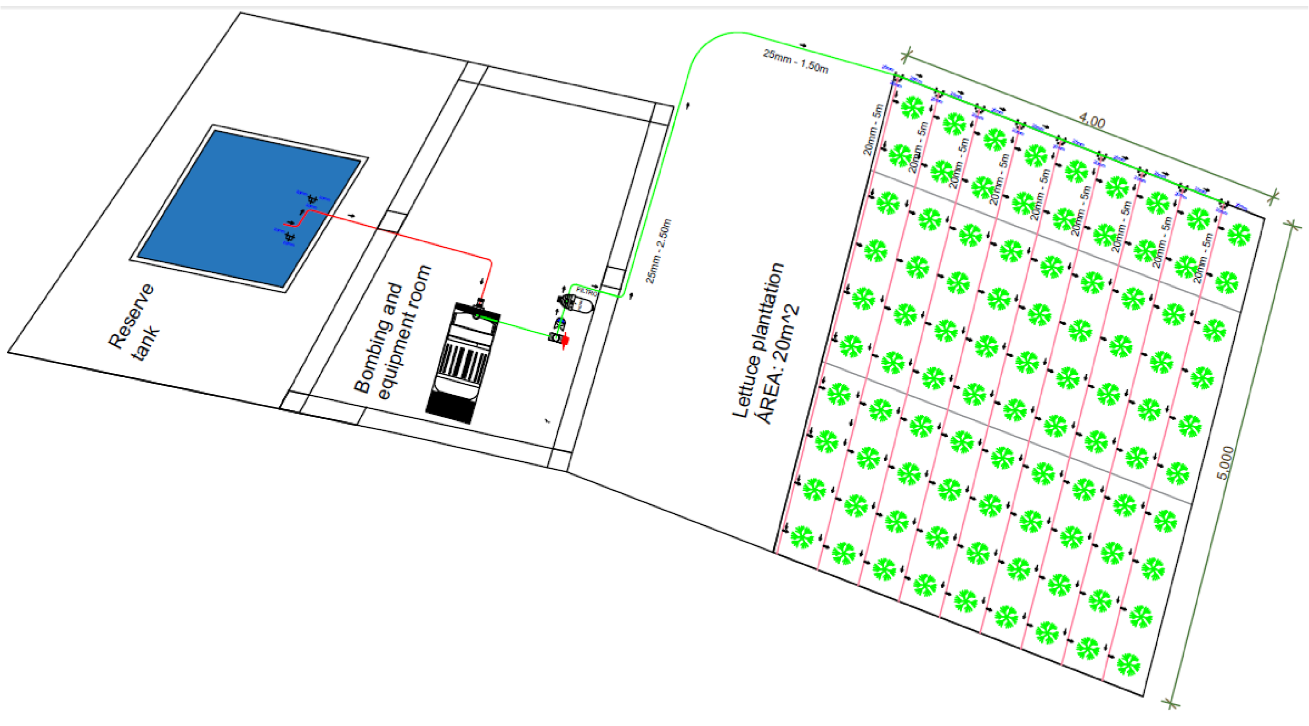

Fig. 2. Lettuce plantation details

The solar irradiation value of 3.66 kWh/m².day is considered for calculations, which corresponds to June with panels tilted at 10 degrees to the North. The daily energy demand of the irrigation and monitoring system is 662 Wh. Then, the number of panels (Np), capacity of the battery bank (Cbb), charge controller, and inverter is calculated.

$$Np = \frac{Energy}{Pmodule * Field\ Efficiency * Irradiation} = 4$$

$$Cbb = \frac{Daily\ Energy\ Demand\ \times Days\ of\ autonomy}{Batery\ bank\ voltage\ \times\ Depth\ of\ discharge} = 237Ah$$

Due to the meteorological situation in the location, a water pumping system was incorporated to irrigate the lettuce crop. The pump power is calculated.

$$Pb = \frac{Q * g * \rho * hb}{746 * \eta} = 0.4\ [hp]$$

Where, Pb is pump power in hp, Q is the water flow rate in m^3/s, g is the gravity acceleration m/s^2, ρ is the water density in kg/m^3, and hb is the pump net head in meters.

Table I: Sizing of the pumping system

Event [%]	Flow m^3/s	D [m]	v [m/s]	N_R	h_f [m]	h_b [m]	P_b [Hp]	P_b [kW]
100%	0.000803	0.02	2.55	49900	6.4432	41.0346	0.54	0.4043
90%	0.000723	0.02	2.30	45007	5.2206	33.7146	0.40	0.2990
60%	0.000482	0.02	1.153	29940	2.3203	16.3732	0.13	0.0968
50%	0.000401	0.02	1.275	24950	1.6113	12.1341	0.08	0.0598
30%	0.000241	0.02	0.765	14970	0.5801	5.9683	0.02	0.0176
20%	0.000160	0.02	0.51	9980	0.2578	4.0415	0.01	0.0080

3. Results and Discussion –

The PV modules were installed on a 4 metre-high metal structure as shown in Figure 3, to avoid shading and to allow free accessibility to the agricultural works.

Fig 3, PV structure for agrovoltaic system and hydraulic system

The PV System consists of the equipment and devices which have a total cost of 1720 USD.

Table II: Cost and economic indicators of the project

Referential equipment costs (Battery charge controller / Inverter / Battery / Solar Panels)	$ 1,720.00
Material costs (Metallic structure, Switches, Switchgear, Grounding systems)	$ 236.00
Transportation and Labor	$ 435.00
Internal rate of return	11%
Net Present Value	728.14%
Return on Investment	9.09 years

In order to compare the results, two samples were taken, one corresponding to the traditional crop and the other to the AVS, as seen in Figure 4. The lettuce produced by the AVS increased in size and their ripening time was shorter. The lettuce of the traditional crop takes three months to be ready for consumption, while those cultivated underneath and feed by the AVS system, took only two months.

Fig. 4. Production of lettuces, left (traditional crop), right (using AVS)

In local markets, traditionally grown lettuces was sold for 0.3 USD, those produced by the AVS are sold for 0.5 USD because of their robust size. Previously, the same parcel of land produced only 60 plants where the farmer obtained 18 USD with the sale of his production. With the implementation of the AVS, his productivity increased to 125 plants, obtaining 62.50 USD, which means an increase of 44.50 USD for the farmer.

4. Conclusions –

The use of an AVS improves crop quality, increasing the sell price of lettuces from 0.3 USD to 0.5 USD each. The payback period has been determined to be a little longer than 9 years, and it has been determined that could be interesting, especially when there is no grid power availability.

Further work would be to identify the improvement in crop production because of the shading produced by the photovoltaic panel. This analysis was not performed in this work due to the small scale of the system; however, on a large scale its benefits can be better quantified.

AVSs are a good alternative to combine power generation with agriculture, considering that these two industries require space that can be optimized under this scheme. It provides the potential to reduce production costs by generating its own electricity. These advantages make the adoption of AVS an appealing and financially rewarding option for farmers.