Energetic analysis and economic assessment of the integration of photovoltaic panels in a greenhouse plantation in Baixo Alentejo

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October 2020

Abstract

With the recent legalization of *Cannabis Sativa L.* for medicinal purposes in Portugal, the interest of several national and foreign companies for the plant´s cultivation in the country spiked due to its favorable climate, the profitability of the product, and its geopolitical location. Based on data from cannabis facilities in countries such as the United States or Canada, it was observed that this industry consumes a significant amount of energy and elects the use of non-energy efficient equipment rather than the investment in more sustainable alternatives.

In partnership with the startup *GreenVitro*, a cannabis greenhouse project in Alentejo Litoral was analyzed considering energy consumption estimates associated with artificial light supplements, indoor temperature control equipment, and water pumping equipment. Some energy efficiency measures were implemented such as the use of a cooling system during the hours of greater solar radiation with a humid cloth over the greenhouse.

The energy and financial relevance of installing a photovoltaic system for the installations' own consumption were analyzed. The derived results showed that the analysis performed is in accordance with other industry's data. Also, there is financial and energy feasibility of applying photovoltaic production to mitigate the high energy consumption of this type of crop, proven by financial indicators such as the internal rate of return and net present value. The storage of energy from photovoltaic production has proved unreliable.

Keywords: Greenhouse; Energy consumption; Self-consumption; Photovoltaic panels; Medical cannabis; Financial analysis.

Introduction

Cannabis' medicinal purposes first discoveries date back to 3000 B.C. in China, Egypt, and India [1] , [2]. Currently, different preparations of the plant are used to treat symptoms related to different pathologies such as chronic pain, muscle spasms, depression, anxiety, post-traumatic stress, loss of appetite derived from treatment for HIV-AIDS and cancer [2]. In 2018, 23 European countries had a legal framework in which it was possible to access cannabis-derived treatment. These countries are joined by Canada, Israel, and 50% of the United States of America, with the list tending to grow. [3]

With a sales price of 3.00 euros/g, medicinal cannabis is one of the most profitable agricultural products today. According to a study on the profitability of a one-hectare greenhouse cannabis plantation in Greece with an initial investment of 4,960,044 €, in the tenth year of activity, the net present value (NPV) is 45,425,241 € and an investment return rate (IRR) of 94.4%. [4]

Cannabis Sativa L. is originally a plant with an annual life cycle of Asian origin. With consecutive human cultivations, it is now planted all over the world with much shorter life cycles and in different ways. For millennia it has been used as a source of fibers for construction and clothing, for food, and medicinal purposes. Only in the last century has its recreational use gained popularity [5].

Cannabis is called a short-day plant: it starts its life in spring and blooms when the night period is longer than the day, usually marked by the arrival of autumn. Given the photosensitivity of the plant, cannabis growers use light control mechanisms to shorten the life cycle of the plant and achieve higher yields. These mechanisms are artificial light supplements and light-deprivation systems [5].

The cannabis grow cycle can be defined by the following stages:

Stage name	Hours of light	Duration of the stage
Germination	18h to 24h	14 days
Vegetative	18h	21 days
Flowering	12h	10 weeks

To obtain a homogeneous production it is usual to use clones in the cultivation of Cannabis Sativa L. This process starts in the "mother plants", a female plant that is part of the genetic portfolio of plants of a producer. It is in the interest of the growers to keep the mother plants in a vegetative state, an almost perpetual state in which the plant continues to grow without producing flowers and allows the removal of clones in specific time intervals without affecting their well-being. Several eligible branches are cut and then transplanted into pots with a suitable substrate for root growth.

Until the near past, large producers did not share their cultivation data with the scientific community and most of the data such as energy consumption and water consumption for irrigation came from apprehensions of producers in the clandestine market. Today it is possible to collect more data from legitimate producers, and there are still many obstacles stemming from the bureaucracy involved, the disclosure of trade secrets, and the complex medicinal-recreational aspect of the plant.[6]

In the state of Colorado in the U.S.A. in 2017, there were 1300 cannabis producers. Of these, 75% planted cannabis inside buildings and consumed 300 gigawatt-hours of electricity per year that reflected in 2650 kWh per Kg of flower produced (1200 kWh/pound). Of the costs associated with a cannabis plantation, between 20% and 50% are energy costs when, for example, in beer production, they represent between 6% and 12% [7]. A typical indoor plantation is equipped with lamps of 600 to 1200 W connected between 8 to 24 hours a day whose operation releases heat to the plantation space. This heat must be eliminated with air conditioning and ventilation systems with considerable power. It is estimated that the indoor plantations reach 2000 W/m^2 of energy consumption. [8]

In a representative internal production, the energy costs can be divided in:

56% - HVAC (Heating, ventilation, and air conditioning)

38% - Artificial light

3% - Irrigation

2% - Injection of CO_2

1% - Flower Drying

With the constant increase of the human population, the consequent technological advance, and globalization the human being as a species needs more and more energy to satisfy its needs [9]. It was Becquerel in 1839 who first observed the photovoltaic effect on semiconductor materials. They are defined by having two energy bands: a valence band that allows the presence of electrons and a conduction band that does not allow them. The most common semiconductor material is Silicon which is characterized by the presence of 4 interconnected electrons. With sunlight, enough energy is supplied so that the outermost electron passes from the valence band to the conduction band generating electricity [9].

There are several advantages pointed out for photovoltaic energy such as:

-The robustness of the photovoltaic system

-The low maintenance cost

- High availability

-The generation of energy can be made closer to the final consumer

-It does not produce noise.

Aim

Given the legalization and consequent exponential interest in medicinal cannabis in Portugal by producers, doctors and potential patients associated with the growing climate awareness experienced, it is considered pertinent to study the energy consumption of this production and to study whether solar panels will be a viable alternative to make cannabis production more energy and financially sustainable. To this end, the following procedures were established:

- Energy analysis of a 1 hectare greenhouse plantation of *Cannabis Sativa L*. for medicinal purposes, in collaboration with the company *GreenVitro*, for which artificial light, Heating, Ventilation and Air Conditioning (HVAC) and other equipment of lower power will be taken into account.

- To estimate the energy needs for each stage and, consequently, identify opportunities to increase energy efficiency, taking into consideration the optimal temperature and light conditions for cultivation in the different phases of the plant's life cycle.

- With the results of the energy analysis, a photovoltaic panel system and other systems for energy generation will be modularized, considering the available area.

Methods

The chosen methodology is divided into five parts:

-Assess the conditions of solar irradiation and outside temperature at the site.

-Dimensioning the artificial light, HVAC and water pumping equipment.

-Analyzing the energy consumption of the greenhouse facilities.

-Design a photovoltaic project with and without storage of energy.

-Measure its financial and energetic viability.

To estimate the hourly outside temperature there will be applied the algorithm "New algorithm for generating hourly temperature values using daily maximum, minimum and average values from climate models" [10]. This algorithm has as input values the daily maximum temperature, the hour that it occurs and the same data for the minimum values. It gives an estimate of the hourly temperature for the duration of the day. This will be employed once per month assuming the days at each month are equal regarding temperature and radiation.

The data concerning the input values of the algorithm were download from [10] and were acquired in a meteorological station located 6 Km from the site.

Due to the scarcity of data on the effective hourly solar irradiation in the coordinates, the following procedure was performed every month of the year:

-Consult data of the hourly ideal irradiation, adding them up to obtain the daily ideal irradiation per month.

-Consult data of the average daily effective irradiation per month.

-Divide the daily effective average irradiation data by the daily ideal irradiation data obtaining a correction factor per month and multiply it by the hourly ideal irradiation data obtaining an estimate of the effective hourly irradiation.

Two forms of heat exchange between the greenhouses and the outside will be considered: radiation on the form of solar irradiation and conduction between the greenhouse cover and the outside air. To this heat is added the heat emitted by light supplement lamps. This procedure is crucial for the sizing of the HVAC equipment, since they are responsible for keeping the indoor temperature within the optimum range for plant growth.

$$\mathrm{Q}(t, M) = \mathrm{A}rea_{cover} * \left(T_{outside} - T_{greenhouse}\right) * U + \mathrm{Volume} * \rho * (T_2 - T_1) * c_p$$

$$+\mathrm{A}rea_{horizontal} * I_e(t, M) * f + Q_L(t, M)$$

The total heat in the hour t, month M, $\mathrm{Q}(t, M)$ is composed by the sum of:

-The conduction heat, computed by the total area of the cover, $\mathrm{A}rea_{cover}$ times the difference of temperatures, $T_{outside} - T_{greenhouse}$ times U, the heat transfer factor.

-The heat from the variation of the inside temperature of the greenhouse that is calculated by multiplying the Volume per the specific mass of the air, ρ times the difference of temperatures in analysis, $T_2 - T_1$ times the specific heat of the air c_p.

-The radiation heat, computed by multiplying the horizontal area, $\mathrm{A}rea_{horizontal}$ by the effective irradiation, $I_e(t, M)$ and the factor of transmissivity f.

-Finally, it is added the heat of the supplemental lighting system, $Q_L(t, M)$.

The total heat per hour is analyzed and annulled by an industrial heat pump per greenhouse with the according heating and cooling powers.

Regarding the supplemental lighting system, the methodology is:

-Size the number of plants per unit of area so that all are easily accessible by the farmer and the leaves have access to natural and artificial light.

-Define the type of lamp to be used (LED, HID, CFL, etc).

-Assume the light intensity in lumens/m^2 per lamp given by the manufacturer as the optimal value for plant development.

-Calculate the number of lamps needed for each of the greenhouses by dividing the area planted by the area advised by the lamp manufacturer for the phase of the plant under analysis.

-With the hourly irradiation data, converted from Watt/$m^2$to lumens/$m^2$and corrected by the transmission factor of 60% [11] that represents the effective light that crosses the greenhouse coverage, calculate the number of hours that the lamps have to be on daily for the optimal lumens/$m^2$to be reached.

-Calculate the energy produced in the form of heat by the lamps and introduce the data in the calculation of the heat exchanged between the greenhouse and the exterior to proceed with the dimensioning of the temperature control equipment.

The electrical consumption of the facilities is estimated by the sum of HVAC, pumping and artificial light consumption, given by the manufacturers, for the 3 greenhouses under analysis.

To proceed with the choice of one of the 3 photovoltaic modules from different suppliers, the criterion of maximization of the power generated per euro invested [W/euro] is applied. A brief study about the best angle for the modules will be done analyzing the ideal irradiation yearly.

There will be projected two options of photovoltaic systems: one with energy storage and one without. To size the projects each monthly consumption will be divided by the production of one module with the following restrictions:

-In the project without energy storage the work will be done in the hourly consumptions of the facilities, with regard for the efficiency of the inverter and modules.

-In the project with energy storge this division is made with the daily consumption and the daily production of energy, regarding the batteries' efficiency in a Charge-Discharge cycle.

To do the financial analysis will be used the Net present Value (NPV), the Internal Return Rate (IRR) and the Payoff Period of the projects. The NPV is equivalent to the project´s monetary value on the current year, obtain by the sum of the costs and the profits related to the project actualized with the discount rate of the year in which it´s from applied from year one to the last year of the project life time. A financially good project has a positive NPV. The IRR is the fictitious discount rate to obtain a null NPV. If the IRR is bigger than the real discount rate the project is financially attractive. Finally, the Payoff period is the first year in which the project has a positive NPV. To address the costs of these projects the methodology will be:

-Acquire the costs of purchasing the components of the photovoltaic system: batteries (in project with energy storage), modules and an appropriate inverter.

-Estimate the Soft Costs: costs related to transportation, installation, insurance and maintenance of the projects.

-Cost of energy to a big consumer in Portugal hourly along the year.

Is necessary to consult the price of the project without photovoltaic production energy purchase and selling energy to the national grid to estimate the energy profits

Results

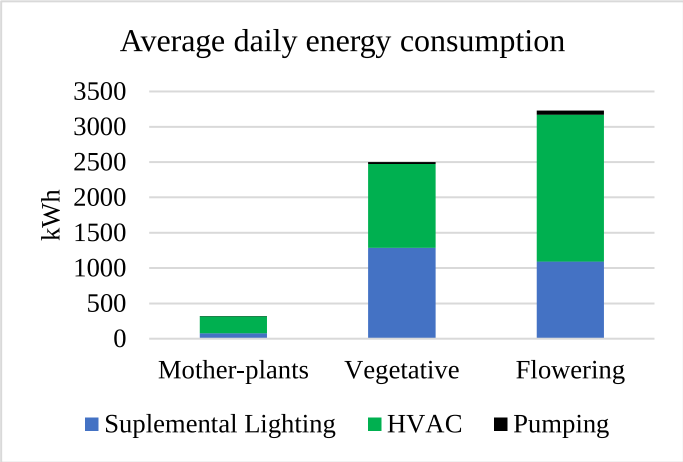

Figure 1 Average daily energy consumption in MWh/day

The energy consumption data show that on average, the mother-plant´s greenhouse consume 319,7 kWh per day, being 238,7 from HVAC equipment. Regarding the vegetative greenhouse the total consumption rises to 2501,9 kWh/day with HVAC and Supplemental lighting equipment having 47% and 51% of the consumption, respectively. The biggest greenhouse has a consumption of 3231,0 kWh/day with 2077,9 kWh being from the HVAC equipment.

Regarding the entire facilities, the HVAC is the major consumer with 57,9%, followed by the supplemental lighting system with 40,6% and the pumping only responsible for 1,5%. In a year, the facilities consume 2,2 GWh of energy, 53,4% of which being from the Flowering greenhouse, 41,3% from the Vegetative and 5,3% from the Mother-plants greenhouse. January is the month with more energy consumed: 7062 kWh/day. The month with less energetic necessities is March with only 4632 kWh/day.

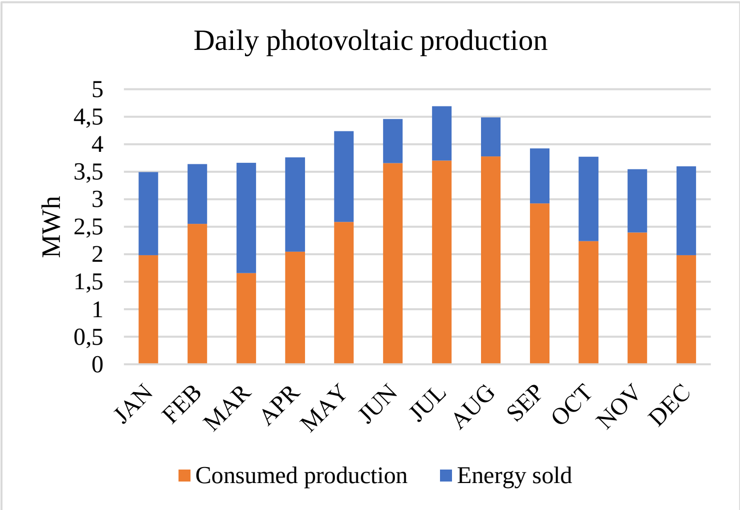

Figure 2 Daily photovoltaic production

Regarding the project without storage of energy, was chosen the ABB megawatt station PVS800-MWS 1 MW inverter and 1770 modules Axitec AC-350M/156-72S are installed. The installation angle of the modules changes 2 times a year: 13,85º from March 30 to September 9 and 51,99º from September 10 to March 29.

In the first year this system produces 1439.7 MWh of energy, the maximum in July with 4.69 MWh/day and the minimum in January with 3.49 MWh/day. 481 MWh are sold to the national energy network. In terms of energy surplus, the maximum is in March with 2.0 MWh/day of energy going for sale and the minimum in August with 0.7 MWh/day that are not consumed.

The annual energy consumption is 43.3% satisfied. The month in which most of the consumption is satisfied with the photovoltaic production is June with 67.9% while in January 72.0% of consumption is not satisfied by the photovoltaic production.

Table 1 Auxiliary calculations for the financial indicators

year	0	1	2	8	9	25
Investment	-333,0 k€	0€	0	0€	0€	0€
Soft costs	- €	- 10,3 k€	- 10,3 k€	- 10,3 k€	- 10,3 k€	- 10,3 k€
Energy costs without P.V.	0€	70,6 k€	70,6 k€	70,6 k€	70,6 k€	70,6 k€
Energy costs	0€	-37,1 k€	-37,1 k€	-37,4 k€	-37,5 k€	-38,2 k€
Energy sold	0€	24,0 k€	23,7 k€	21,6 k€	21,2 k€	15,5 k€
IRC	21,5%	21,5%	21,5%	21,5%	21,5%	21,5%
Energy profit after IRC	0€	18,9 k€	18,6 k€	16,9 k€	16,7 k€	12,2 k€
Cashflow	-333,0 k€	42,1 k€	41,8 k€	39,8 k€	39,5 k€	34,3 k€
Actualization rate	1	0,98	0,96	0,89	0,87	0,66
Actual Cashflow	-333,0 k€	41,4 k€	40,4k€	34,9 k€	34,0 k€	22,6 k€
Net present Value	-333,0 k€	- 291,5 k€	- 251,0k€	- 28,2 k€	5,9 k€	**448,3** k€

The project with photovoltaic production without energy storage has an energy cost of 37 112.48 euros in the first year and a sale of 24 072.42 euros before the IRC is applied. The project without photovoltaic production would have an annual energy cost of 70 616.34 euros.

In the project without energy storage the NPV after 25 years is 448 259.84 euros, the IRR is 11.0% and the period of return on investment is 9 years. The LCOE of this project is 0.016 EUR/kWh.

Considering the values of NPV, IRR, LCOE and period of return on investment the project chosen is the project without energy storage with 1770 photovoltaic panels in which for 25 years 33 404.14 MWh of energy are produced. In the year 25, the NPV and the IRR values for the storage option are negative.

Discussion

A consumption per year of 2 209 MWh was estimated for the installations. This translates into 147.3 kWh/(m^2-yr) of energy for a greenhouse area of 15 000 m^2.

This indicative value is in accordance with a study carried out in the state of Colorado in 2018 to producers of recreational and medicinal cannabis greenhouses: 129.12 kWh/(m^2-yr) (original value: 12 kWh/ft^2) [12]. Comparing the values attributed to the different types of consumption we can see that 53.5 kWh/(m^2-yr) were used for HVAC and pumping while in GreenVitro's project this value goes back to 87.5 kWh. This discrepancy in values may be linked to the nature of the plantation: some of the producers plant cannabis for recreational purposes which eliminates some technical elements of a pharmaceutical grade product.

It is noted that the amount invested per installed capacity of the GreenVitro project is in accordance with the Corinthia Hotel project and the theoretical study conducted [13], [14]. The Amareleja power plant has a 42% lower investment per kW installed compared to the GreenVitro project. This figure is explained by the fact that Amareleja has 73 times more installed power and consequently has access to another unit price of equipment. [15]

The results for the IRR and return on investment period agree with the other authors. It is possible to observe a discrepancy with the study of the Hotel Corinthia explained by the low photovoltaic production and the investment in modules for a vertical facade.

The calculated value for the LCOE of the GreenVitro project was 0.016 EUR/kWh. This value is not realistic because it is only about 42% of the calculated value for the Amareleja plant, a plant with more than 45 MW of installed power whose cost per kW installed is lower. This discrepancy may be due to several factors such as:

-An unrealistic calculation of photovoltaic production over the lifetime of the project, which would be in accordance with the data in the table comparing energy indicators.

-A faulty investment estimate.

Conclusions

The legal intensive cultivation of cannabis in a greenhouse or indoor mode is an emerging and recent industry (<10 years) and has a heavy energy load associated with artificial light supplement equipment and environmental control system within the plantation space.

Taking into account the validation of the results, the energy analysis performed is in accordance with actual data from licensed producers even if they were not considered consumption related to plant drying, light machinery, dehumidification or office energy consumption.

The photovoltaic production project with energy storage indicated that a battery system would not be financially sustainable. The market for energy storage from photovoltaic production is evolving with new technologies, better loading and unloading efficiencies and in price per kWh of storage. Associating this with the fact that in this study several factors that could influence the final result such as the price of other accessory equipment to a storage system have not been considered and that an intensive search among suppliers of the best market price for this type of system has not been made, the negative financial result may not be valid and its validity may change within 5 years.

The photovoltaic production project without energy storage elected revealed that the production estimated at 25 years is higher than the production of other similar projects revealing some wrong hypothesis that was assumed in the solar irradiation data or in the analysis of the data provided by the manufacturers of photovoltaic modules/inverter.

This same project proved to be financially attractive with an 8-year return on investment and a 11.0% rate of return on investment, according to the data from other authors, but these figures should be examined with caution since the cost of energy produced is much lower than others from the production of similar photovoltaic projects.

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