ECONOMIC ANALYSIS OF A PHOTOVOLTAIC ENERGY SYSTEM IN THE ACTIVATION OF HYDROPONIC SYSTEMS

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Abstract: The expected increase in the energy consumption in the coming years could lead to the depletion of energy resources compromising among other sectors the guarantee of food production in Brazil. Therefore, with the need for sustainable production photovoltaic energy is a promising alternative that can be combined with a sustainable form of production that is the hydroponic cultivation. In this sense, this work was developed with the objective of evaluating the economic viability of a photovoltaic energy system in the activation of a hydroponic bench. For this, two hydroponic benches with the same characteristics were considered differing each other for the form of pumping the nutrient solution, one of them maintained in a conventional pumping system connected to the electrical grid and the other with a pumping system activated by photovoltaic energy. From the survey of the mean cost value and the life expectancy of the equipment as well as the hourly cost of the conventional electricity it was possible to determine the total hourly cost of pumping of each system. The results showed that the adoption of the photovoltaic energy system provided an 87.6% reduction in the pumping costs compared to the system when using conventional electricity.

Index terms: Cost; solar energy; hydroponics; sustainability.

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INTRODUCTION

The frequent increase in the world population, the speed of urbanization and the depletion of natural resources require a sustainable form of food production (Retief et al., 2016). In this sense, one of the foundations of an economically sustainable country is its ability to provide the logistics and the energy necessary for the development in safe, competitive and environmentally sustainable conditions (Tolmasquim and Guerreiro, 2014).

Brazil has its energy matrix marked by the use of fossil inputs such as oil and coal which constitute a scenario of scarcity and environmental impacts. The electricity sector is basically supplied nowadays by hydroelectric and thermoelectric sources which cause relevant environmental impacts. The expected increase in energy consumption for the coming years may make these resources not sufficient to support the expected growth, causing concern on a global scale and bringing challenges to the searches for possible new sources of energy generation (Silva et al., 2018).

This situation has led countries to seek new forms of energy production that are less harmful to the environment and more economically viable. Development strategies have been directed towards the use of renewable energies which, in addition to reducing emissions, are becoming economically viable (Rosa and Gasparin, 2016).

In recent years, the generation of electricity by photovoltaic systems has had considerable growth worldwide due to the reduction in its implementation cost and also the notable reduction in conventional electricity consumption resulting from the expansion of photovoltaic systems (Pitzcker et al., 2014). The highlight for this energy source is the favorable geographic position of Brazil which allows for a good rate of solar radiation. According to Pinto (2018) the less sunny region of Brazil has about 1,642 kWh/m^2 of energy while, for example, the sunniest region of Germany has only about 1,300 kWh/m^2 of energy.

In Brazil, wich is one of thre sunny countries in South America, the capacity to carry out large-scale investments without subsidies and financing by consumers is inferior to that of the developed countries and should be taken into account in feasibility studies. The main factors that determine the economic viability of photovoltaic systems compared to conventional systems are the amount of solar energy that reaches the earth's surface, the final cost per peak Watt (Wp) installed and the operating and maintenance costs (Green and Stephen, 2017).

Lettuce (*Lactuca sativa* L.) is cultivated mainly by small farmers, being one of the most consumed leafy vegetables in Brazil and with productive potential throughout all the year long under adequate conditions of water and soil nutrients (Valeriano et al., 2018). In the search for production techniques that contribute to reducing environmental impacts, hydroponics has gained prominence over the years. In this alternative plant cultivation technique, the soil is replaced by a nutrient solution thus favoring the best development of leafy vegetables allowing for better production efficiency and consequent product quality.

The production of Lactuca sativa L. fits as the one used on a larger scale by the hydroponic cultivation called NFT - "Nutrient Film Technique" or laminar flow of solution among plants (Jardina et al., 2017; Santos et al., 2020).

Among its advantages, the production in a hydroponic system ensures higher quality and integrity of the material produced when compared to the field production and can considerably increase its shelf life in addition to adding value for its clean production method. (Nascimento et al., 2011; Neto and Barreto, 2012).

However, besides the inconvenience of a high initial investment, this production system depends on a pumping system that guarantees the flow of the aqueous solution, which is normally activated by electricity which causes a great impact on the cost in addition to the risk of damage from failures in the supply of electricity. So, the need to explore other energy sources is considered as a way to improve the hydroponic system. Hernández-Moro and Martínez-Duart (2013) highlight that photovoltaic technology is viable for small and medium projects that require electricity to pump the water used in agriculture. However, as stated by Souza and Gimenes (2018), the adoption of renewable energies such as photovoltaics, despite representing an important advance towards energy sustainability, requires the implementation of support policies and incentives for its use. Although the interest on the part of rural producers in joining the use of photovoltaic energy, it is observed that the high investment cost is still considered as a barrier to the massification of this form of energy.

Brazil has a high renewable energy potential but the cost assessment to ensure the feasibility of implementing alternative energy systems must be considered. Thus, this work was developed with the objective of evaluating the economic viability of a photovoltaic energy system in the activation of a hydroponic bench compared to the use of conventional electrical energy.

MATERIAL AND METHODS

This work was developed in the horticulture sector of the Federal Institute of Education, Science and Technology of the South of Minas Gerais (IFSULDEMINAS) – Campus Machado Campus, 21º41'57.09" S Latitude and:

45º53'11.01" W Longitude with 907m altitude. The climate of the region is Cfa, according to the KOPPEN classification, with an average annual temperature of 19.8°C and annual precipitation of 1590 mm.

The data were obtained in a hydroponic system pumping house with the production of flat lettuce, located in a greenhouse 27 meters long and 14 meters wide, with a ceiling height of 3.5 meters, under a 200 micro plastic cover, 50% side shading screen.

The experiment was carried out using two hydroponic benches with the same characteristics differing for the form of pumping the nutrient solution with one bench maintained in a conventional pumping system connected to the electrical grid and another with a pumping system activated by photovoltaic energy, constituting the two essays, objects of the experiment.

The conventional pumping system (Essay 1) (Figure 1) is composed by the following componentes: time Electric power source, timer, relay and motor pump.

According to the literature and information from manufacturers a period of 5 years is defined for the life expectancy of motor pumps, 6 years for time programmers and 7 years for contactors (Akikur et al., 2013). The energy used to activate the motor pump was from the local electrical grid supplied by Companhia Energética de Minas Gerais – CEMIG. The pumping system with photovoltaic energy (Essay 2) (Figure 2). This system is composed of the following components: photovoltaic module, charge controller, timer, energy storage battery, and motor pump.

According to the literature and information from manufacturer a period of 30 years is defined for the components of this system for the life expectancy of photovoltaic panels, 5 years for batteries and motor pumps, 6 years for time programmers and 10 years for charge controllers (Shayani et al., 2006).

In photovoltaic pumping systems flows can vary according to the level of solar radiation incident on the solar plate and consequently there may be difficulty in maintaining stability at constant flows justifying the adoption of a battery in order to maintain the voltage requirements and the working current of the DC motor and keep without oscillations in a power source with 12 V voltage.

A survey was made to obtain the average value and the life expectancy of the equipment used in the two systems for later determination and comparison of the hourly costs of each technology. The hourly cost of each the equipment of both systems was calculated by Equation 1 and then, the total hourly cost of equipament was obtained by the somatory of them.

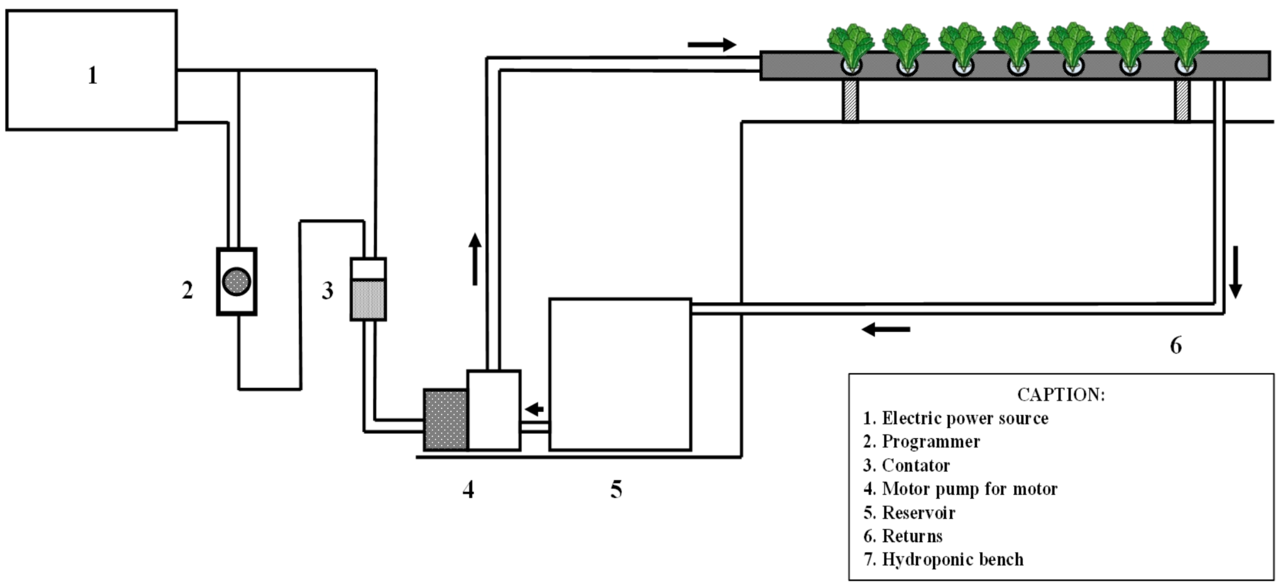

Figure 1: Experimental arrangement of the conventional pumping system and its components. Machado – MG, 2021. Source: Own authorship.

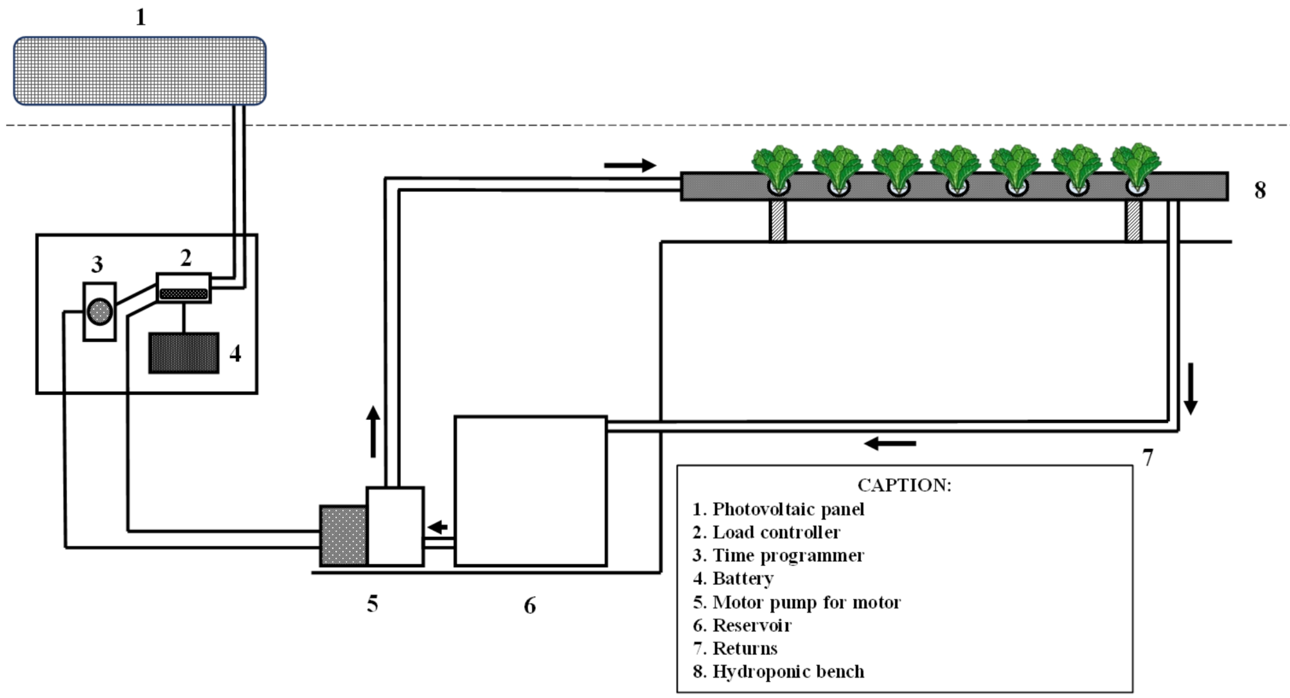

Figure 2: Experimental arrangement of the photovoltaic pumping system and its components. Machado – MG, 2021. Source: Own authorship.

$$CE = \frac{ACE}{LUE} \quad (1)$$

where:
CE = Hourly cost of each equipment for each system (R$.h^{-1});
ACE = Acquisition cost value of each equipment used (R$);
LUE = Life expectancy of each equipment used (h).
R$ = Reais (Brazilian currency).

As there is no cost of electricity in the photovoltaic system, the total hourly cost of this system is equal to the hourly cost of the equipment according to Equation 2:

$$CPS = CE_{PS} \quad (2)$$

where:
CPS = Total hourly cost of the photovoltaic system in Reais per hour (R$.h^{-1});
CE_{PS} = Cost of the equipment in the photovoltaic system in Reais (R$);

For the conventional system it was necessary to consider the hourly cost of electrical energy which can be determined by Equation 3. The electrical energy consumption was measured using a digital wattmeter previously calibrated with a known electrical charge.

$$EC_{CS} = \frac{V_{EE} \cdot C_{EE}}{T} \quad (3)$$

where:
EC_{CS}= Hourly cost of electricity in the conventional system (R$.h^{-1});
VEE = Value of electricity charged by the energy concessionaire (R$.kWh^{-1});
CEE = Energy consumption in the period in kWh
T: equipment operating time (h)

The total hourly cost of the conventional system as a function of the cost of the equipment and the energy cost from the electricity company was determined by Equation 4:

$$CCS = EC_{CS} + CE_{CS} \quad (4)$$

where:
CCS = Total hourly Cost of the conventional system, in reais per hour (R$.h^{-1});
ECc_{S} = Hourly cost of electricity in the conventional system (R$.h^{-1});
CE_{CS} = Total Hourly cost of conventional system equipment (R$.h^{-1}).

The electrical energy consumed (kWh) by the two systems was monitored for a period of 10 days and the daily mean values of consumption were submitted to T Student's test with a (1- α) significance level of 99%.

RESULTS AND DISCUSSION

Electricity consumption data for both systems are presented in Table 1.

Table 1: Statistics of the mean values of the electricity consumed for both systems

Treatment	Convencional system	Photovoltaic system
Consumed energy (kWh)	329.96 a	51.87 b
Standard deviation (%)	3.07	4.06
Coefficient of variation (%)	0.93	7.83

Different letters in the lines indicate a significant difference between treatments at the significance level (1- α) of 99% by Student's T test.

As the conventional system is supplied by the electrical grid the voltage variation established by the National Electric Energy Agency and the manometric height of both hydroponic systems were constant. The small variation among the mean values for the conventional system was the naturally expected result. The difference in energy consumed between the two systems was due to the unavailability of a lower power pump to activate the conventional system and this difference was considered in the discussion of results. The mean market values, the live expectancies and the hourly costs of the components of each system are expressed in Table 2.

The values presented in Table 2 summarize the acquisition cost of R$1,051.73 for the conventional energy system and of R$1,389.80 for the photovoltaic energy system based on retail prices in the domestic market. An aggravating point in the use of solar energy is the fact that the costs of implementing photovoltaic systems are still very expensive (Silva et al., 2020). However, according to Souza and Penha (2020), when studying cash flow projection they observed that the investment in a photovoltaic energy system with a life expectancy of up to 25 years proved to be attractive when verifying the payback time of the investment from the fifth year of use. This means that the investment is able to bring positive cash flows in just 20% of the life expectancy of the system. Thus, photovoltaic generation significantly reduces the cost of electricity in all sectors of the economy and adds value to the property in addition to the possibility of a return on investment (Araújo et al., 2019).

As suggested by Shayani et al. (2006) a more accurate comparison of the costs between the solar energy and other sources can be made using technical criteria such as its investment value diluted over its entire life expectancy. In

Table 2: Mean market value and service life and hourly cost of conventional and photovoltaic system components. Machado - MG, 2021. Source: Own authorship.

Conventional system			
Components	Mean value (R$)	Life expectancy (Years)	Hourly cost (R$ h^{-1})
Motor pump	859.06	5	0.0196
Programmer	115.00	6	0.0022
Contactor	77.67	7	0.0012
Electrical energy	--	--	0.0183
Total cost	1051.73		0.0413
Phtovoltaic system			
Components	Mean value (R$)	Life expectancy (years)	Hourly cost (R$ h^{-1})
Motor pump	523.25	5	0.0119
Programmer	75.00	6	0.0014
Battery	110.09	5	0.0025
Charge controller	87.74	10	0.0010
Photovoltaic panel	593.72	30	0.0023
Total cost	1389.80	--	0.0191

relation to the hourly cost of the motor pump the value obtained was R$0.0196 h^{-1} for the conventional system and for the photovoltaic system was R$0.0119 h^{-1}. The contactor and time scheduler elements for the conventional system had the hourly cost of R$0.0012 h^{-1} and R$0.0022 h^{-1}, respectively.

In the photovoltaic energy system, the battery had an hourly cost of R$0.0025 h^{-1}. On this issue, it is important to add that the use of batteries associated with panels for energy storage has been an alternative since photovoltaic systems with battery integrated to the inverter have the possibility of generating energy during the day and storing part of it (Rodrigues and Rampinelli, 2020). Thus, it is possible to improve the energy availability by replacing the battery with one with higher power, ensuring higher system autonomy by expanding its capacity to work for several hours without interruption even on cloudy days.

This possibility of increasing autonomy in the photovoltaic system is of great importance because, according to Silva et al. (2010) and Zen and Brandão (2019), in the installation of hydroponic systems a limiting factor to consider is the possibility of power outages, a common fact, especially in rural areas, which can often reflect the need to adopt complementary systems which reflect greater complexity both in the planning of the structure as in the installation and programming of the system. Thus, the producer must be aware of the supply of all external resources because depending on the support structure in his production context this can become another important inconvenience. The hourly cost of the charge controller was of R$ 0.0010 h^{-1}, the photovoltaic panel cost was of R$ 0.0023 h^{-1} and the hourly programmer cost was of R$ 0.0014 h^{-1}, totaling an hourly cost of R$0.0191 h^{-1} for the energy system photovoltaic.

The cost of electricity in the conventional system was of R$0.0183 h^{-1}, representing 44.3% of the total cost of this system. Thus, the cost of the conventional electric power system was 2.16 times more expensive than the photovoltaic system. In other words, the adoption of the photovoltaic system represented a 53.75% reduction in the hourly cost. In results obtained by Brunini et al. (2019) the cost of the photovoltaic irrigation system represented a saving of approximately 83.30% when compared to the conventional one.

However, as shown in Table 1, the conventional system pump was oversized in relation to the photovoltaic system pump. If we look for fairness in the comparison of systems, we can simulate the existence of a pump in the conventional system with identical power to the pump in the photovoltaic system. Under these circumstances, the energy consumption would be the same for both systems and the cost of electricity in the conventional system would reduce to R$0.0029 h^{-1}. Even with the significant reduction, the hourly cost of the conventional system would still be higher, i.e., R$ 0.00259 h^{-1}, approximately 1.35 times more expensive than the conventional system.

Despite the higher initial expenses with the integrated system (hydroponics - photovoltaic energy), the producer will have higher financial return in the medium and long term, spending the least amount of water and energy resources, leading to a total reduction in fixed expenses and increasing their profitability, without leaving aside the vision of the environmental sustainability (Araújo et al., 2019).

CONCLUSIONS

The purchase of equipment for the photovoltaic energy system requires higher initial investment.

The cost of electricity supplied from the electrical grid was the highest impact factor on the total cost of the hydroponic system activated by the conventional energy.

Under the conditions of the experiment the adoption of the photovoltaic system reduced by 53.75% the costs of activating the hydroponic bench compared to the conventional electrical system.

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