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# PHOTOVOLTAIC PLANT TO SUPPLY ENERGY FOR AN ELECTRIC COFFEE DRYER - ENERGY COSTS AND COMPENSATION

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**KEYWORDS**

*Coffea Arábica L.*, distributed generation, energy pricing, grain drying, post-harvest, photovoltaics.

**ABSTRACT**

In this work, we sought to minimize electricity costs in the coffee bean drying process by carrying out the theoretical sizing of the economic viability of the Photovoltaic Power plant (PVP) ongrid used to supply a Dryer Unit (DU). The methodology consisted of adequate sizing of a PVP generation plant to promote the electric energy balance. It used economic indicators such as internal rate of return, discounted payback, and net present value. Two scenarios were considered: a pessimistic with DU use on-peak period; and an optimistic with full use of the DU during the off-peak period. It was considered local electricity tariff values, and the results indicated the economic feasibility for the PVP installation also the feasibility of the dryer use in both scenarios, there are no restrictions on operating hours. It can be concluded that it is essential to understand the Brazilian electricity bill legislation because only in this way is it possible to properly develop the on-grid photovoltaic power plant projects. The technical and economic parameters are inseparable and indicated that the electricity tariff should not exceed US\$ 0.22 $(kWh)^{-1}$ to ensure the photovoltaic power plants installation viability to supply DUs that remain in operation during on-peak periods.

## INTRODUCTION

### Coffee grain drying processes.

Coffee drying is based on the removal of water from the beans to reduce their metabolic activity to increase their longevity and ensure their quality and physiological stability. The conventional method of drying is the terrace, where the grains are exposed to direct sunlight, being susceptible to dust and pathological agents brought by the wind or animals, in addition to being vulnerable to rain and being dependent on weather conditions. Dryers can be used to condition the grain mass in air-injected environments. Most of these types of equipment heat the air to increase its evaporative capacity. (Resende et al., 2011; Oliveira et al., 2011).

Among the air treatment techniques adopted in mechanical drying, is air heating with thermic demand as: wood, wood chips, Liquefied Petroleum Gas (LPG), and biogas; however, the development of dryers that use electric energy showed the use of generation from photovoltaic systems, which can be fed with their own (and renewable) energy.

Firewood and wood chips are the most economically accessible renewable energy sources to be converted into thermal energy, but they present large variations in the drying air temperature, linked to the supply of the furnace. (Simioni et al., 2018).

LPG offers simplicity in operation and good air temperature control. Biogas can present variations in methane content, promoting variations in the heat transmitted to the air mass. (Galbiatti et al., 2010).

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Electricity emerged together with new drying techniques, in this study a Dryer unit (DU) was used that dehydrates or before its study and subsequent insertion in the dryer. In this case, the mixture is cooled to a temperature below its dew point to remove water and reduce its proportion. Subsequently, the air is heated, causing its waters to have enthalpy, unlike the pressure of removal of water from the grains.

The DU is composed of a drying Air Treatment Unit (ATU), which promotes dehydration and heating. The ATU in this study has an installed electrical power of 148 kW and a refrigeration capacity of 363,636 kcal $h^{-1}$, it is coupled by ducts to a set of 5 Tray Dryers (TD) with an individual drying capacity of 15 $m^3$. (Konopatzki et al, 2022)

The components of the DU are shown in Figure 1.

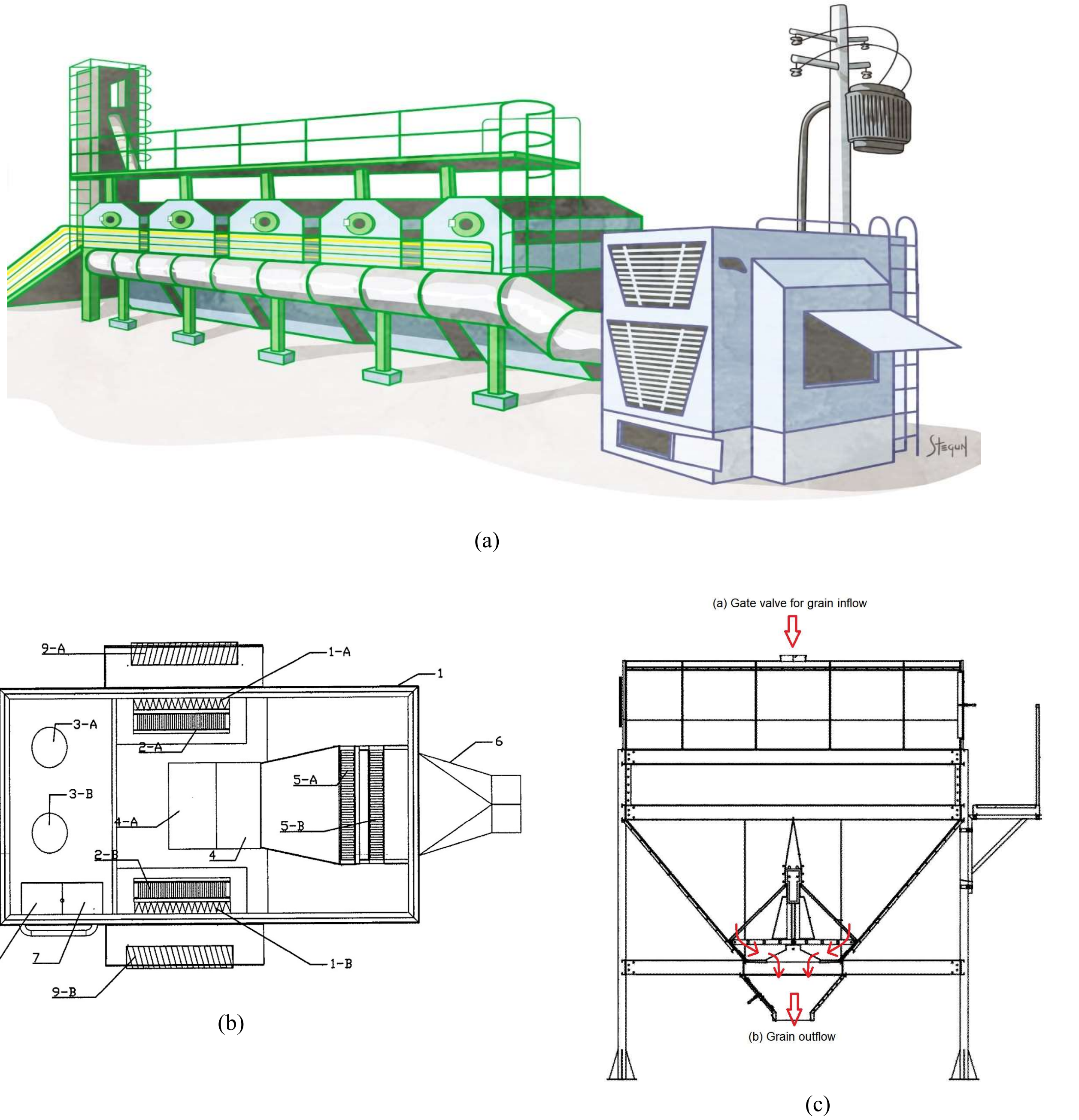


FIGURE 1. Representation of the drying unit with an air treatment unit and 5 tray-type dryers (a), Representative diagram of the air treatment unit (b), and Side section of the tray-type dryer (c).

Source: Adapted from Konopatzki et al. (2022)

Note: 1: In Figure 1 (b): ADH metal structure body; 1-A and 1-B: Pleated air filters with a great capacity for the retention of air, dust, and dirt; 2-A and 2-B: Evaporator coils; 3-A and 3-B: Compressors; 4: Fan; 4-A: Fan motor; 5-A and 5-B: Condenser serpentines; 6: Drying air outflow ducts; 7: Control panel; 8: Power table; 9-A and 9-B: Dumpers (two) outdoor air intake. (a): grain entrance valve. (b): mechanically moved valve.

In Figure 1 (c): To fill the module, the grain entrance valve (a) is opened, and the grain flow occurs when the base of the plate's "w" is mechanically moved (b).

The ATU used in this study has two evaporator coils and two condenser coils connected by a set of compressors that can be operated separately. The ventilation system causes ambient air to enter the ATU, which passes through the coils and is directed to the outlet duct for drying, see Figure 1 (b).

The DU ones are dimensioned for the static drying of 75 m$^3$ of coffee. Each module consists of a drying tank with a retractable bed, and the coffee in the trays is arranged in a "W" shape, see Figure 1 (c). The trays are perforated and the air passes through the beans in an upward flow.

Choosing the best combination (energy source and method) implies analyzing not only the technical effects but also the economic effects of each project. Konopatzki et al. (2019) stated that dry coffee in this DU has higher quality and better selling price, the authors found an increase of 12.11% in the added value of coffee.

**Photovoltaic system planning at this DU**

A photovoltaic system consists of a generator, power conditioning, and, optionally, storage. Grid-connected photovoltaic systems do not require a storage system, as the energy produced can be instantly consumed by the load or injected into the electrical grid.

In the generator module, there are photovoltaic cells, several cells are grouped to produce photovoltaic panels. Cells are normally connected in series to produce higher voltages. Photovoltaic systems can employ many modules connected in series and/or parallel arrangements to produce the desired amount of electrical energy.

Series connections are known as strings to provide the proper working voltage. Then the strings are connected in parallel to increase the power of the system.

Photovoltaic solar modules generate energy in direct current, being necessary to use DC-AC converter equipment, the alternating voltage and current must present characteristics of frequency, harmonic energy, and typical waveform suitable to the regulations imposed by the regulatory agency. (Brazil, 2021).

The sizing of inverters must be compatible with that of photovoltaic modules, to avoid oversizing, which is clipping on the inverter power curve, as shown in Figure 2.

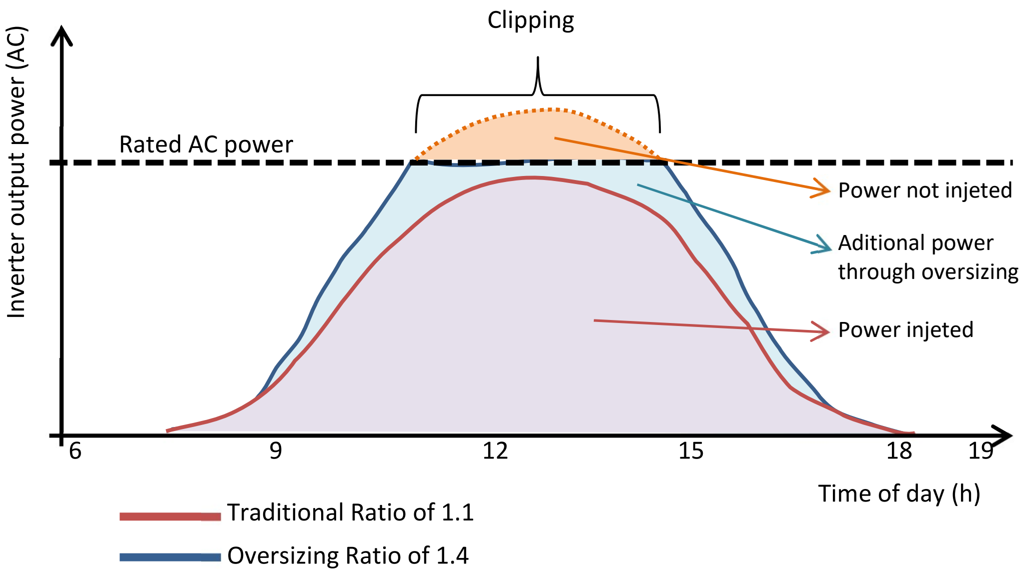


FIGURE 2. Oversizing and clipping on ten inverter samples.
Source: Adapted from Souza (2019).

Oversizing can be used to maximize the generation of photovoltaic energy, so that the rated power of the inverter is reached for a longer period, widening the generation curve, consequently, obtaining more energy generated. (Souza, 2019)

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Series connections are known as strings to provide the proper working voltage. Then the strings are connected in parallel to increase the power of the system.

Photovoltaic solar PV arrays generate energy in direct current, being necessary to use DC-AC converter equipment, the alternating voltage and current must present characteristics of frequency, harmonic energy, and typical waveform suitable to the regulations imposed by the regulatory agency. (Mihir & Paresh, 2019)

**Brazilian model of distributed generation**

The National Electric Energy Agency (ANEEL) is the regulatory body for electricity tariffs - which must be fairly expressed to energy consumers and guarantee resources to cover operating expenses and improvements in productivity, energy quality, customer service, concessionaires, and distributed mini generation, formed by systems with a total installed load between 75 kW and 5 MW. (Brazil, 2021).

According to Brazil (2021), the electrical energy Tariff ($T$) considers three different costs, Generated Energy ($GE$) the Transmission and Distribution Structure ($TDS$), and the Sectorial Charges ($SC$), as shown in eq. (1)]:

$$T = GE + TDS + SC \tag{1}$$

In addition to tariff costs, electricity distributors collect, through the energy bill, federal taxes: Social Integration Program (SIP) and Social Security Financing Contribution (SSFC), state: Tax on the Circulation of Goods and Services (TCGS), and municipal: Public Lighting Contribution (PLC). Taxes are mandatory payments made to the government, based on legal determination, and which guarantee resources for the Government to carry out its activities. (Brazil, 2015).

The costs of electric energy distributors are classified into two types: The first of them is called "Portion A" and is given by the purchase of energy, transmission, and sector charges. The second type is "Portion B", which represents the energy distribution. (Brazil, 2015).

Captive consumers served at medium and high voltage belong to group A, with binomial pricing. The electric service voltage of 230 kV (or higher) is classified in subgroup A1, between 88 and 138 kV in subgroup A2, 69 kV in subgroup A3, between 30 and 44 kV in the A3a subgroup, and, finally, between 2.3 and 25 kV in the A4 subgroup. (Gehrke et al., 2021).

Group A consumers can be classified into two types of tariffs, per the consumption of electricity and/or demand active power: (Muñoz et al., 2017).

a) Green Tariff Modality: Available for subgroups A3a and A4, with the Final Tariff (FT) represented by the quantities Consumption Tariff (CT) and Measured Consumption (MC) both at peak hours (PH) and off-peak hours (OPH); Demand Tariff (DT); and Demand Charged (DC), according to [eq. (2)]:

$$FT = (CT_{PH} * MC_{PH}) + (CT_{OPH} * MC_{OPH}) + (DT * DC) \tag{2}$$

b) Blue Tariff Modality: Mandatory for consumers in subgroups A1, A2, or A3, and optional for consumers in subgroups A3a or A4. In this case, there is the DT magnitude both in the peak hour and in the off-peak hour. The final tariff is given by [eq. (3)]:

$$FT = (CT_{PH} * MC_{PH}) + (CT_{OPH} * MC_{OPH}) + (DT_{PH} * DC_{PH}) + (DT_{OPH} * DC_{OPH}) \tag{3}$$

Distributed generation is characterized by the generation of electricity on a small scale, usually from renewable sources or using fossil fuels, implemented in the centers of electricity consumption. (Brazil, 2021)

The main advantages found with the installation of small generators in the electrical system are the postponement of investments in expansion in the distribution and transmission systems; minimal environmental impact; and the diversification of the Brazilian energy matrix. (Brazil, 2015).

The necessary conditions for distributed generation and the electricity compensation system were stipulated. All equipment that makes up the distributed generation system, as well as its installation, is the responsibility of the consumer. To measure the generated and consumed energy, it is necessary to install a bidirectional meter, which is the responsibility of the distributor, at no cost to the system user, in the case of distributed microgeneration. (Galvão et al., 2018).

According to the National Electric Energy Agency (Brazil, 2015), the Brazilian tax regulation on electricity includes the Tax on Circulation of Goods and Services (ICMS), the Social Integration Program (PIS), and Contribution to the Financing of Social Security (COFINS).

These taxes are levied on distributed mini generation, with emphasis on ICMS, based on the percentage recorded on the energy bill, which is charged on excess energy generated and injected into the electrical grid.

In the case of a distributed mini-generation system, the consumer is responsible for repaying the concessionaire for the costs of adapting the metering system. (Cardoso et al., 2021).

a) PIS and COFINS: With the publication of Law No. 13,169/2015, the collection of PIS and COFINS has changed, being applied only to the positive difference between the energy consumed and energy injected by the Eletcricity Consumer (EC) with micro or mini distributed generation. Because they are federal taxes, all Brazilian states are required to apply this law in full. This positive difference is a favorable incentive for the consumer who owns the photovoltaic generation because, before the law, the consumer paid this tax on his own generation.

b) ICMS: To make distributed generation economically viable, the National Council for Finance Policy (NCFP) published the ICMS Agreement 16, of 4/22/2015, which authorized state governments to grant an exemption on the circulation of electricity. Therefore, ICMS is applied only to the amount that differs between the energy injected into the grid and the energy consumed. This action was also a favorable incentive for the consumer who owns the photovoltaic generation.

The municipal tax, referring to the contribution of public lighting, is normally charged. In the months in which the energy consumed by the EC is less than the energy injected, a credit in kWh is intended for the consumer, to deduct consumption at another address of the consumer (for consumers with horary tariff) or in the invoice of the following months. The validity for using the credits is 60 months. (Cardoso et al., 2021).

This system allows the generation of surplus energy produced in the EC to be injected into the distribution network, that is, the distribution system works like a battery storing energy. The main innovation was the electricity compensation system, shown in Figure 3.

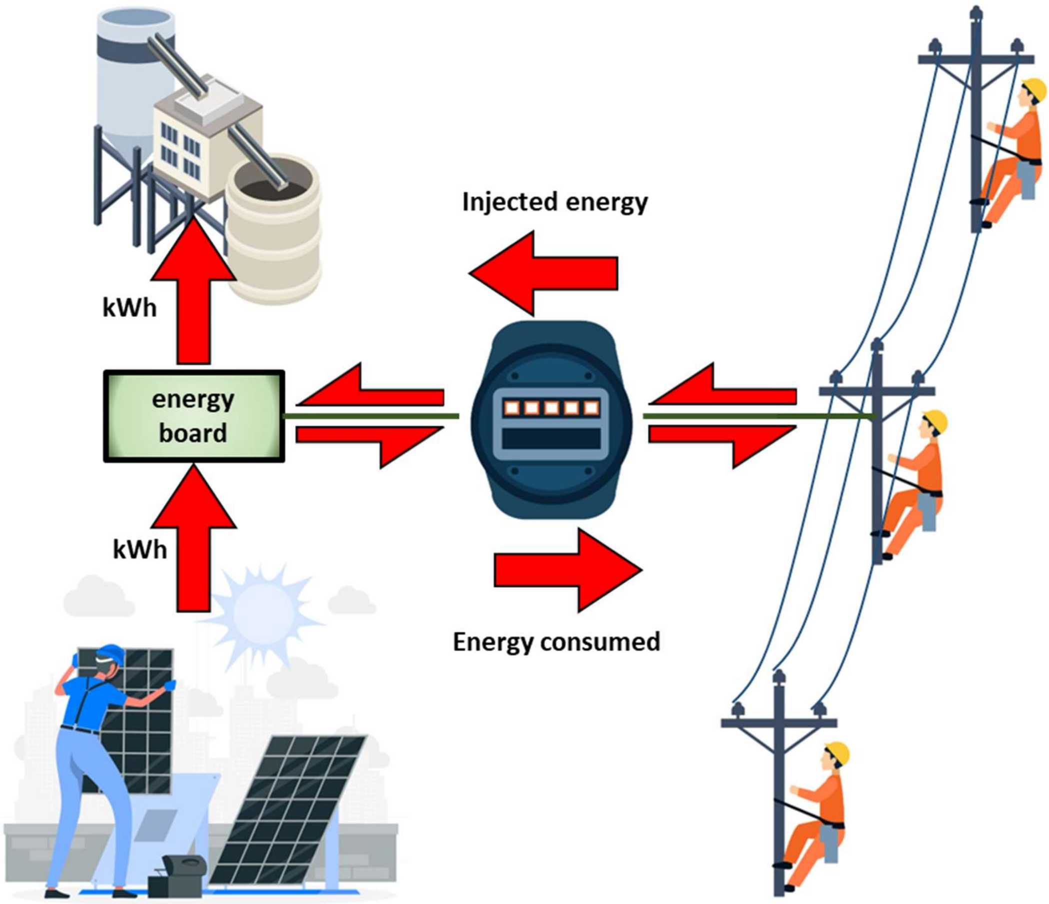


FIGURE 3. Representation of electric energy flow for compensation bank.
Source: Adapted from Cardoso et al. (2021).

Consumer Unit (UC) it can also be seen, by checking Figure 3, that when the UC does not generate enough for its supply, the local distribution concessionaire will make up the difference, first with the use of credits, when there are.

The compensation system for Group A consumers provides that the excess energy injected at a especific horary tariff (peak or off-peak), will necessarily compensate for the energy consumed at that same horary. If there is still a surplus, by applying an adjustment factor, the credits are used to offset consumption at another time. (Cardoso et al., 2021).

There is no minimum amount to be paid for distributed mini generators, however, the demand bill is usually charged, with taxes and without any changes.

The problem presented in this study is to dimension a PV system that presents technical and economic feasibility for drying coffee with an electric dehumidifier and air preheater unit, considering the value of demand and energy tariffs, taxes, and the value added by the quality top of dry coffee in this US.

## MATERIAL AND METHODS

This study presents a quantitative approach to climate data, harvest periods, acquisition costs of photovoltaic solar PV energy generation systems, and electricity expenses in the Franca, São Paulo (BR), with coordinate SAD69: - 22.21, - 49.66; Araraquara, São Paulo (BR), with coordinate SAD69: - 21.79, - 48.18; Garça, São Paulo (BR), with coordinate SAD69: - 20.54, - 47.42 and São Tomás de Aquino, Minas Gerais (BR), with coordinate SAD69: - 20.78, - 47.10, between the years 2017 and 2020.

The classification of the nature of scientific research considers such an approach as one that employs standardized and systematic measures, seeks predetermined answers and facilitates the comparison and analysis of statistical measures of data. (Nunes et al., 2016).

The mean daily solar irradiation of the cities analyzed was presented in Figure 4

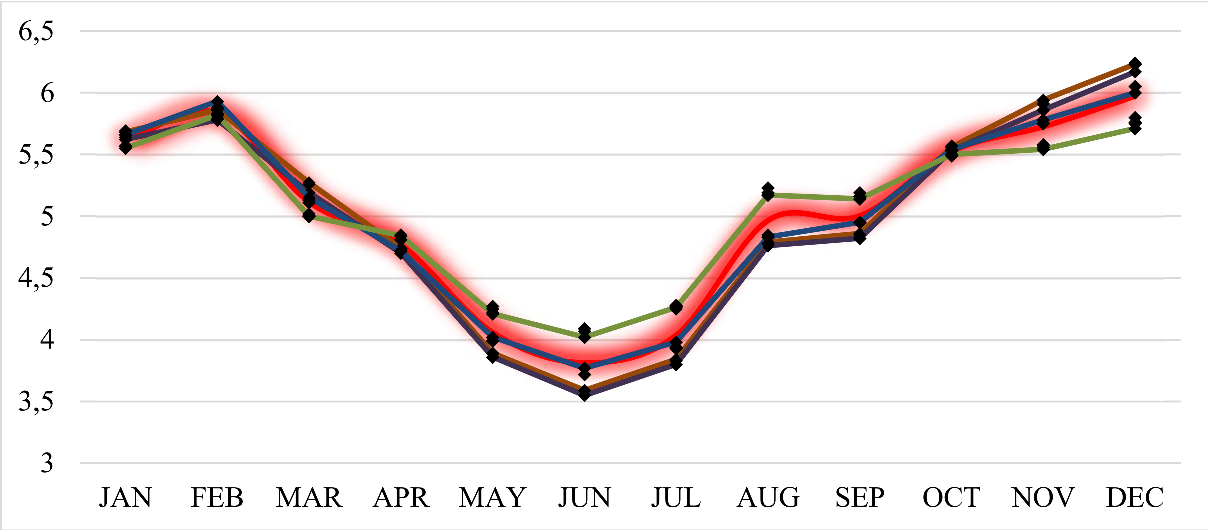


FIGURE 4. Mean daily solar irradiation, in kWh/m$^2$.day.
Adaptaded from CRESESB (2018).

The irradiation was 5,0365 ± 0,1252 kWh.m$^{-2}$.day. This value was used to calculate the peak power of the PV system. To achieve the objective proposed in this study, whose characteristics are to design a photovoltaic power plant to supply the electric energy of the DU using the annual seasonality, the steps described below were adopted.

**Gains and expenses of using the electric coffee dryer**

It was found that the dry coffee in the DU showed a gain in its quality, which implied an average appreciation of 12.11% in the sale price (Konopatzki et al., 2019; Konopatzki et al., 2022). The average value of a bag of Arabica coffee - Physical Market (Type 6, Hard Drink) on 08/01/2022 was US$ 4.26 kg$^{-1}$. Implying that the appreciation of dry coffee in the DU results in a financial gain of US$ 55,261.60 year$^{-1}$. The amount considered in the cash flow revenue considered the conversion of BRL 5.67 for 1 US$ (01/07/2022).

The energy consumed by the UD, to dry 75 m$^3$ of coffee with initial humidity of 50% (wet basis) to 11% of humidity, in the average drying time of 8 h daily during 9.2 days. Being able to manage up to 16.3 batches per year and remain connected for 1,450 hours per year, concentrated in the months of May to September (coffee harvest period in the states of São Paulo and Minas Gerais). (Konopatzki et al., 2022).

Based on the data characterized by Konopatzki et al. (2022), it was estimated the consumption of 172.63 MWh of electric energy by the studied drying system. This same value was used as a reference for the annual generation of the photovoltaic system.

The tariff framework chosen in this study was the group "A" (high voltage), subgroup "A3a" (medium voltage service of 34.5 kV), and "green" tariff modality, characterized by charging a single demand value at any time of the day. The average values of demand tariffs, off-peak energy, and energy at peak hours will be presented in the next sections.

In this study, two scenarios were considered: scenario 1 (pessimistic) with the DU uses at on-peak period and scenario 2 (optimistic) with DU uses just at off-peak period.

The electricity tariff in Brazil is divided into two periods (Brazil, 2021): peak and off-peak hours. Peak hours are when the demand for electricity is greatest, usually in the afternoon and early evening, between 18 h and 21 h when people get home and turn on their electrical appliances. Off-peak is the period of lower demand, usually during the early morning and early morning. This differentiation is important because electricity distribution companies need to be able to meet the maximum demand, and this implies additional costs. Thus, the electricity tariff at peak times is more expensive than at off-peak. This differentiation is regulated by the National Electric Energy Agency (ANEEL).

It was considered the DU use in the 5 months of harvest and the electrical power of the ATU of 148 kW.

**Composition of annual electricity expenditure in Scenario 1**

The average electricity demand tariff adopted in this study was US$ 5.09 kW$^{-1}$, so was estimated that the electrical demand is responsible for the increase of US$ 3,764,35 in the annual electricity bill of the UC.

The average energy tariff during the on-peak period (between 6 pm and 9 pm) was US$ 0.27 kW$^{-1}$. Thus, DU's electricity is responsible for an increase of US$ 40,056.66 in the annual electricity bill.

**Composition of annual electricity expenditure in Scenario 2**

The value of the average electricity demand tariff, the harvest period (and consequent use of the DU), and the electrical power of the ADH were considered the same as in scenario 1, so the demand for the DU implies the same increase (from US$ 3,764.35) in the annual electricity bill in both scenarios.

The average energy tariff during the off-peak period (between 9 pm and 6 pm) was US$ 0.07 (kWh)$^{-1}$ Since the use of DU increases the annual energy bill by US$ 12,622.94.

**Sizing of the photovoltaic solar power generation system**

The sizing of the photovoltaic power plant was carried out with the PV*SOL Premium software, owned by the German company Valetin Software GmbH, with a temporary trial ware license (30 days) acquired to carry out this work. Brand references do not constitute a recommendation on the part of the authors.

The photovoltaic solar energy generation system was designed to generate, within a year, all the energy consumed by the HU. The dimensioning can exceed this value by up to 10%, to supply any unforeseen technical losses.

In the software, the diodes of the photovoltaic modules (responsible for the direction of the current) were parameterized at 0.5% for the power loss due to the voltage drop; the mismatch effect (loss of module yields due to various factors) of 2.0%; dirt losses in the modules were not considered; the NPV adopted was equal to the average inflation of the last 20 years, 5.91% pa; the energy inflation adopted was 4.9% pa (adjustment received by the concessionaires In the period). (Turco et al., 2019).

Characteristics of the photovoltaic module used in the design of the photovoltaic solar energy generation system was presented in Table 1.

TABLE 1. Photovoltaic Module Characteristics.

| Technical characteristic | Parameter adopted |
|---|---|
| P-type | monocrystalline cell types |
| Cell numbers | 72 |
| Bypass diode numbers | 3 |
| Voltage at PMP | 40.71 V |
| Current in PMP | 13.02 A |
| Open circuit voltage | 49.35 V |
| Short circuit current | 13.71 A |
| Rated power | 530 W |
| Filling factor | 78.34% |
| Efficiency | 20.55% |

Source: Adapted from PV*SOL (2022).

The choice of monocrystalline photovoltaic cells to produce solar energy is justified by their high performance in converting solar energy into electricity. Studies indicate that monocrystalline cells have a conversion efficiency ranging from 18% to 24%, while polycrystalline cells have an average efficiency of 15%. Monocrystalline cells are produced from a single silicon crystal, which results in greater purity and homogeneity of the material, which also contributes to its superior performance compared to polycrystalline cells. (Mihir & Paresh, 2019)

For the sizing of the charge controllers, a nominal power of 25 kW (each), GROWATT brand, with 3 phases, 4 string boxes, and 3 Maximum Power Point Tracking (MPPT) was adopted. The MPPT voltage range/nominal input voltage of 360 V has been parameterized with an input voltage between 250 V and 1,100 V and a 10-year functional warranty.

In the tenth year, the exchange of the inverters for the current value corrected with the same interest rate considered in this study was considered. The value of the inverters was obtained by budgeting with three companies that supply the study region. The value used in this study was US$ 31,141.42 ± 1,658.12.

Turco et al., (2019) indicates that the ideal operating load of the charge controllers was between 100% and 120%, with the following ranges being tolerated: lower between 90% and 100% and higher between 120% and 130%. The optimal power range of string boxes up to 22 kW has been parameterized, with a tolerance level of up to 25 kW. A permissible voltage drops of 4% and power cables with a minimum cross-sectional area of 4 $mm^2$ were chosen.

The composition of the acquisition cost of the photovoltaic solar energy generation system was made by the average of 5 quotes with an inverter within the technical specifications.

The average acquisition value of the photovoltaic solar energy generation plant was US 1.00 $W^{-1}$ (Silva et al., 2019) with the average cost of frequency charge controllers approximately equal to 21% of the total value. Thus, the system has an implementation cost of US$ 148,292.49 in the initial year and a contribution of US$ 31,141.42 in the tenth year of the cash flow.

**Economic analysis**

The economic feasibility analysis of the acquisition of the photovoltaic solar energy generation system was carried out through the economic indicators PBd, NPV e IRR. (Fernandes et al., 2016; Ávila et al., 2017).

The period in which the value of the investment is recovered is called the Payback. The PBd considers the net present value of the cash flow (CFt) and the cost of money (t), that is, the interest rate practiced in the period (p), which can be represented by [eq. (4)].

$$PBd = \frac{CF_t}{(1+t)^p} \tag{4}$$

NPV (Equation (5)) is equivalent to calculating the present value of a sequence of inputs and/or outputs, discounting the interest rate, and deducting the Investment (I). If the NPV result is positive, there is an indication for decisions favorable to the investment, while a negative NPV means that the investment is not attractive.

$$NPV = \sum_{t=1}^{p=20} \left(\frac{CF_t}{(1+t)^p}\right) - I \tag{5}$$

NPV corresponds to profitability or return on investment, for this reason, it is a widely used indicator in economic feasibility analyses. Furthermore, varying the interest rate so that the cash flow presents null NPV conceptualizes the IRR, presented in [eq. (6)], which can be compared to the Minimum Attractiveness Rate (MAR) or to the Interest Rate (IR) to show an intrinsic rate of return. (Newnan et al., 2014)

$$0 = \sum_{t=1}^{p=20} \left(\frac{CF_t}{(1+NPV)^{IR}}\right) - I \tag{6}$$

ROI, presented in [eq. (7)], corresponds to the relationship between NPV (US$) and I (US$). Its result is a dimensionless number that, if greater than 1, shows a financial advantage in the execution of the project, under the defined interest rate. (Konopatzki et al., 2018).

$$ROI = \frac{VPL}{I} \tag{7}$$

Likewise, projects with an ROI lower than 1 can be discarded, and these results show an IRR lower than the interest rate for the project, the result may be positive, but it will not be attractive for investment.

**Considered cash flow**

The cash flow is considered the financial investment for the acquisition of the photovoltaic solar energy generation system using accounting depreciation of 20 years, which is the useful life of the photovoltaic cells. In the period of 10 years, the acquisition of new frequency charge controllers was considered since the supplier informs a useful life of 10 years for these components.

As an annual expense, the electricity bill from the DU was considered. As annual revenue, the increase in the sales value of dry coffee in the DU was considered. In this study, an interest rate of 10.0% per annum was adopted.

The indicators of this study, empirically indicated, are used to recommend the photovoltaic solar energy generation plant when the PBd is less than 10 years, IRR is greater than 15% (per year) and, further, the NPV is positive, and the ROI is not less than 2.

## RESULTS AND DISCUSSION

**Sizing of the photovoltaic system**

When parameterizing the region of São Paulo and Minas Gerais in the PV*SOL software, it was verified that the annual average daily radiations are (in kWh m$^{-2}$): direct = 3.04 ± 0.18; diffuse = 1.81 ± 0.20; reflected = 0.04 ± 0.89 10$^{-4}$ and total = 4.89 ± 0.70, therefore, the annual average daily insolation is 5.3 ± 1.02 h.

The peak power of the PV system was dimensioned with 236 PV shared of 530 W (each) and 5 power inverters with 25 kW (each). The sized photovoltaic solar energy generation system, according to Figure 5, can produce 183,327.83 kWh of electrical energy annually, an amount sufficient to supply the total consumption of the DU. The surplus of energy produced in the months of October to April is compensated in the months of May to September.

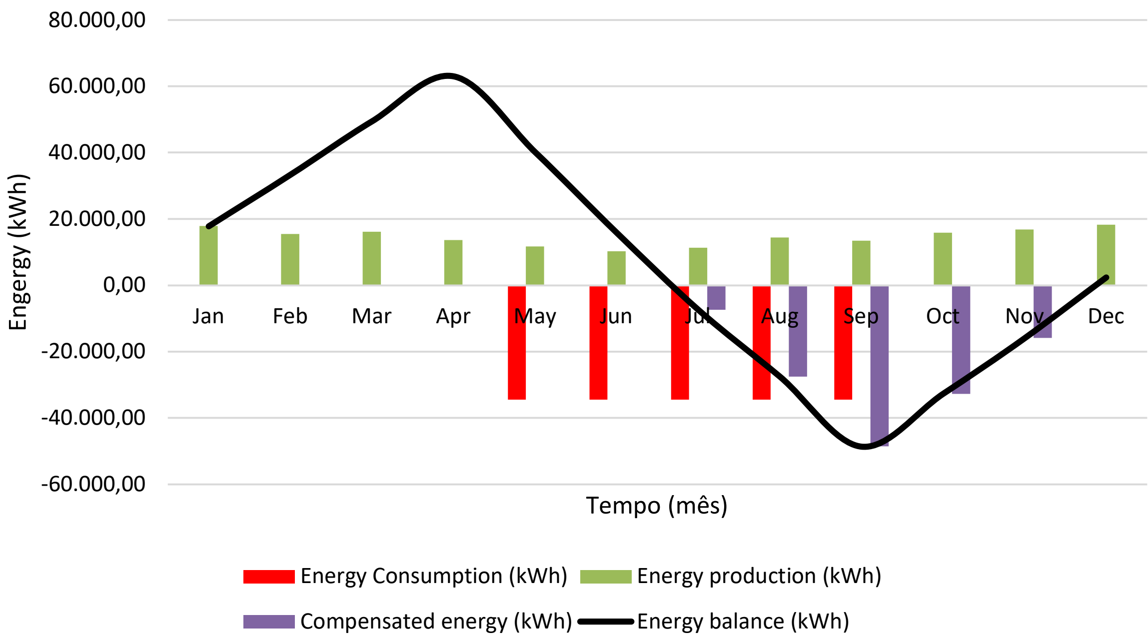


FIGURE 5. Consumption, production, balance, and compensation of electrical energy designed for the consumer unit (UC).

In the months from October to March, the electricity bill will be composed of the collection of the contracted demand plus the related tax, for this reason, the monthly amount of the bill will be increased by US$ 752.87. During this period, the energy generated by the photovoltaic solar energy generation plant (17,060.93 kWh average monthly) will flow toward the electrical grid and will be accounted for as a credit for the UC.

In the months from April to September, for scenario 1, in which the DU works during the 3 peak hours daily and the credits are considered at the cost of TE tariff, US$ 5,909.02 kWh$^{-1}$ average monthly are counted from the EC energy bank to settle the average monthly flow of 21,745.18 kWh.

This effect is perceived in Figure 4 with the descending "energy balance" curve between April and September. In this period, the electricity bills for this period were increased by the demand tariff plus its taxation (of US$ 752.87) and the taxation of the compensated energy tariff (US$ 728.78), with a total monthly increase of US$ 1,481.65.

In the same period (April to September), with the operation of the DU in scenario 2 (daily use during off-peak hours) 21,745.18 kWh average monthly flow from the electricity grid to the CU. Electricity bills for this period will be increased by the demand tariff plus its taxation (of US$ 752.87) and the taxation of the compensated energy tariff (US$ 530.02), with a total monthly increase of US$ 1,282.89.

**Cash flow from photovoltaic solar power generation plant in drying unit**

It was found that the largest investment was that presented in period zero, as it covered the acquisition cost of charge controllers, photovoltaic plates, fixing structures, conductor cables, and labor. In period 10 the acquisition of an inverter was considered, as can be seen in Figure 6.

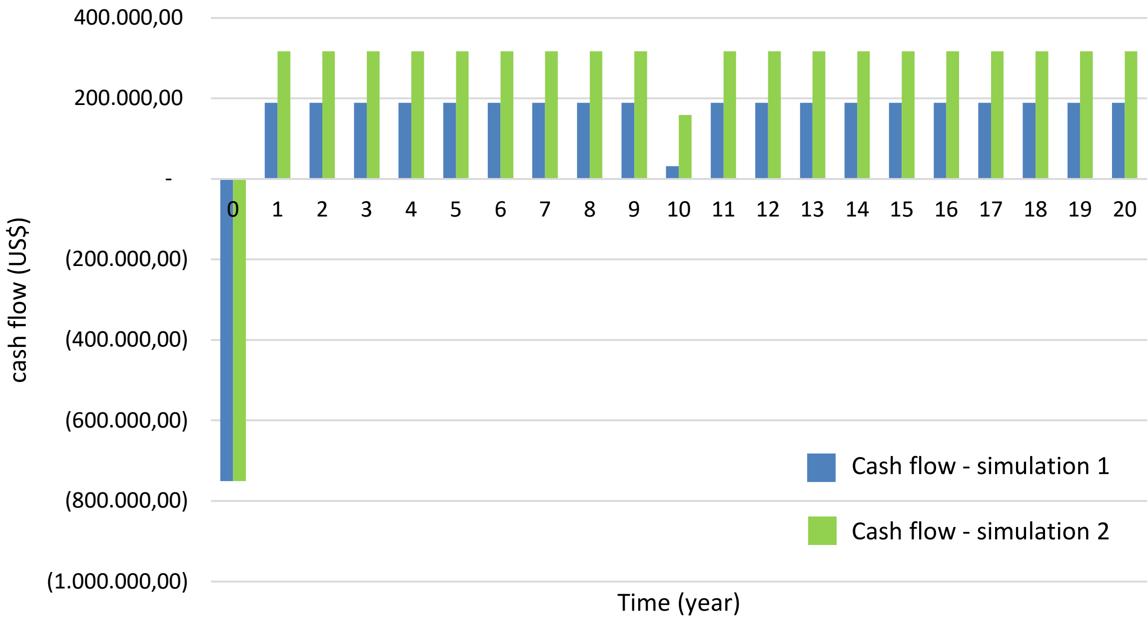


FIGURE 6. Cash flow in simulated scenarios 1: with the drying unit running at peak time and 2: with the drying unit running at an off-peak time.

When the DU is connected at an on-peak period (scenario 1), investing in the photovoltaic solar energy generation system has a Future Value (FV) of US$ 519,196.26, with an IRR of 18.24%. This project has an NPV of US$ 195,679.61 and a PBd of 5.9 years.

By managing the DU operation to work only during the off-peak period (scenario 2), the photovoltaic system has a VF of US$ 1,624,714.33, with an IRR of 41.89%. This project has an NPV of US$ 612,337.74 and a PBd of 2.6 years.

The economic indicators of the two scenarios studied can be seen in Figure 7. The hours of operation of the DU can influence the results of the economic indicators used in this study, making evident the need for monitoring a trained professional to manage the use of the DU. Since the ROI can vary between 1.32 and 4.12 times the amount initially invested.

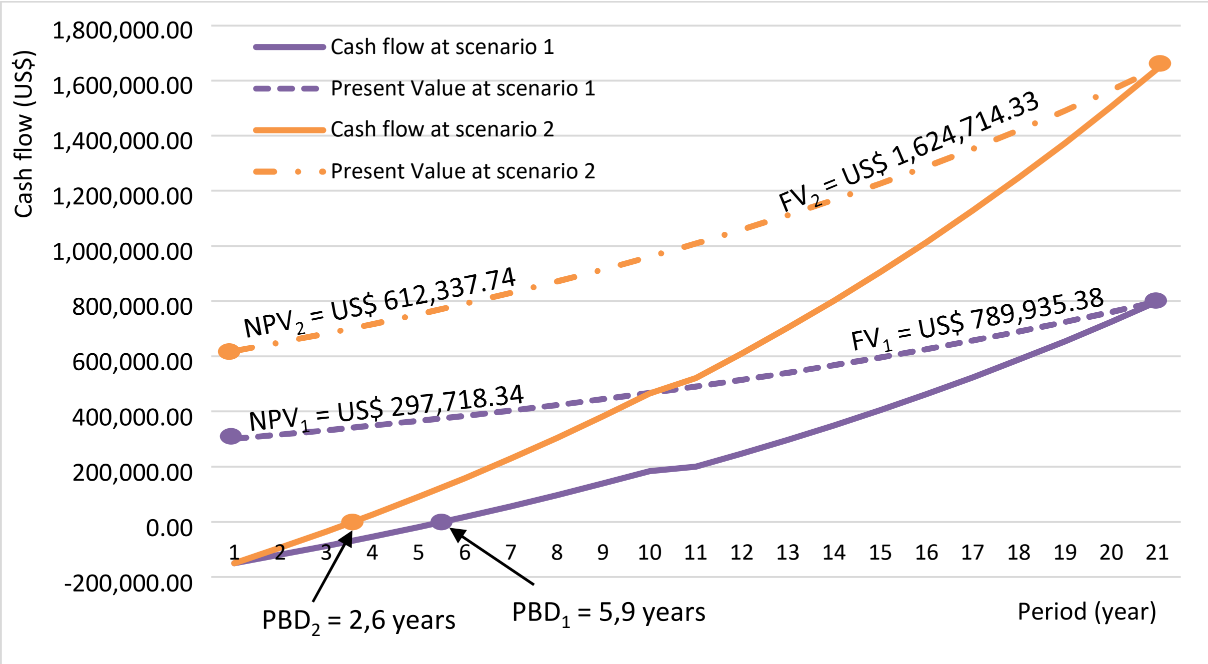


FIGURE 7. Financial projection of the investment in a PV system for the projected scenarios 1: with the drying unit working at peak hours and 2: with the drying unit working at off-peak hours.

Based on the investment recommendation adopted in the methodology, it can be seen that the PBd was less than 10 years for both scenarios, as well as the IRR was greater than 15% per year, and the NPV was positive. The ROI presented a result of less than 2 for scenario 1, indicating that the continuous use of DU during the on-peak period is not indicated.

For this reason, the maximum energy tariff cost of US$ 0.22 (kWh)$^{-1}$ supported by economic indicators was analyzed to guarantee a minimum ROI of 2. Thus, if the electricity tariff reaches this value (0.22 US$ (kWh)$^{-1}$) the following results will be verified for the economic indicators: NPV of US$ 283,541.27; IRR of 24.26%, PBd equal to 4.5 years, and ROI of 2.01.

Ultimately, the energy tariffs were varied until each of the indicators, empirically recommended in this study, was obtained, so it was found that the PBd will be less than 10 years while the tariff is less than US$ 0.32 (kWh)$^{-1}$. The IRR will be greater than 15% per year while the tariff is less than US$ 0.29 (kWh)$^{-1}$, the NPV will be positive when the tariff was less than US$ 0.31 (kWh)$^{-1}$ and, finally, the ROI will not be less than 2 when the tariff is not less than US$ 0.22 (kWh)$^{-1}$.

## CONCLUSIONS

This paper aimed to design a mini photovoltaic power plant to supply the DU electrical energy and analyze the economic viability of its implementation by considering the economic indicators IRR, NPV, PBd, and ROI.

The results evidenced the installation feasibility, especially if the DU is used during the off-peak period (scenario 1), in which the ROI indicator is bigger than 2. During the on-peak period (scenario 2) the ROI indicator will only be bigger than 2 while the electricity tariff remains less than US$ 0.22 (kWh)$^{-1}$.

To obtain these results, it was essential to understand the Brazilian electricity bill legislation. Thus, projects related to distributed generation, renewable energy, and energy efficiency can have an analysis of your performance carried out effectively.

In future works, the authors intend to analyze the economy for the generation of electric energy, comparatively with the network for the scenarios, with and without batteries, in the off-grid and hybrid systems.

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