The cost of electric energy and its relationship with the photovoltaic energy generation system: a case from a rural property of Leme-SP

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Abstract

This study analyzes the economic and financial viability of installing a photovoltaic solar energy production system in a rural property located in Leme - SP, Brazil. The main purpose is to understand how the electric energy tariff variation may interfere with the investment decision. The net present value, internal rate of return, scenario analysis, and Monte Carlo simulation are used to investigate the risks involved in tariff changes imposed by the electric utility and the minimum acceptable rate of return requested by pig producers. To conduct the tests, information about energy demanded by the rural property and the costs of electric energy from 2014 to 2019 were collected to estimate the incremental cash flow. The results show a positive net present value when it is considered an interest rate of 6.5% of return and an internal interest rate of 12% per year. Additional tests also provide evidence that the project risk is lower as the energy tariff increases; however, the Monte Carlo simulation suggests that the investment in the photovoltaic energy system is only interesting for the analyzed pig farming whether the minimum acceptable rate of return is lower than 12.5%. Besides photovoltaic energy is economically viable it also adds better practices to support agribusiness being more sustainable.

Keywords: Photovoltaic energy. Pig production. Monte Carlo simulation.

1. Introduction

The magnitude of agribusiness and pig farming in Brazil is evidenced when the results of the Gross Domestic Product (GDP) generated by agribusiness and the results of the country's Trade Balance are analyzed. Brazil's 2020 GDP of R$7.4 trillion had a 26% participation from agribusiness according to the Center for Advanced Studies in Applied Economics (CEPEA-ESALQ); livestock was responsible for 8.1% of the national GDP. The importance of agribusiness is also reinforced by Brazilian trade balance. According to data published by the Confederation of Agriculture and Livestock of Brazil (CNA), exports in 2020 reached US$ 100.8 billion, the second highest value in the last 10 years. The trade balance of the agribusiness, in 2020, was positive by US$ 87.8 billion, reaching its highest value in history. It is even observed that the sector is responsible for the total Brazilian trade balance surplus in the period, given that, in other sectors, the result was negative between 2017 and 2020.

Brazilian pig farming production occupies fourth position in the world's pork production ranking (4.436 million tons produced) and pork exports (1.024 million tons exported) according to the Brazilian Association of Animal Protein (ABPA, 2020). The ABPA statistics also accounted for 1.970.611 swine sows, an increase of 11,37% from 2019. Likewise, its importance has gained prominence, as in 2020 it practically doubled the export of fresh pork, reaching US$ 1.2 billion dollars. However, even with the record of good prices paid to the farmers, data from Embrapa Swine and Poultry (2020) registered in the months of April, May and June,2020 a negative income, that is, the pig producers presented losses in the activity. In this context of growing importance of hog production, the value chain needs to maintain their competitiveness and decisions on investments that affect the costs and sustainability of the business become important for the viability and profitability.

Pig production costs consist of the inputs for feed, health, facilities, and labor required for the management. Among them are the expenses related to electricity consumption for engines used in the production and movement of food, heating, stall cleaning, and lighting, among others. In this sense, the search for technologies that allow cost reduction and hence increase the profitability of the business is indispensable.

Studies on hog production costs usually compare the relation of variables that compose the cost in some regions and periods, as in Portes et al. (2019) in which the authors analyze the costs of the production chain in southern Brazil or in Moreira et al. (2019) that the swine production cost variables in the Northeast, Midwest, Southeast and South regions of Brazil are considered. Some research estimate costs and analyze the competitiveness of pig farming in Brazil (TALAMINI et al., 2006; SARAIVA, 2012; PONTES, ARAÚJO, SARAIVA, 2015) taking into account data from Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA).

Besides there are studies in other agribusiness production chains that address costs as an important management and strategic positioning tool. As an example, Hofer et al. (2006) highlighted the importance of rural entrepreneurs attempting to minimize production costs, avoid waste and improve planning, control and cost management. In a similar sense, Vellani et al. (2010) evaluated the cottonseed chain, analyzing and comparing scenarios, each one with its expenses, revenues, investments and highlighting the importance of strategic cost management in agribusiness. The present study intends to analyze investments in the organization that enable strategic cost management, in elements that guide the company to make decisions that will determine costs. These resources position the company in a consistent situation, for the development of competences and aiming to obtain competitive advantage, these resources are valuable, unique and inimitable (HOSKISSON et al., 2009; SANTOS,HEXEL, 2005).

For that matter, several technologies have been used to reduce electricity costs. The energy generated by biodigesters, wind, and photovoltaic systems has been used for pig production, the last two also applicable to any type of production as long as the necessary conditions are met. According to Cirino and Faria (2013), a biodigester is formed by a chamber in which swine manure diluted with water goes through the fermentation process, resulting in the production of a liquid effluent (used as fertilizer) and gas (methane), which is used for electricity production. High costs of installation and the variability in the number of animals are factors that make this alternative unviable, as the quantity of pigs needed for the production of residues and biogas is a limiting factor of the project, besides the number of equipment demanded by the system. (MARTINS; OLIVEIRA, 2011).

According to Alves (2010), the wind power generation system “uses the kinetic energy formed in the moving air masses. Its operation converts the kinetic energy of translation into kinetic energy of rotation.” The use of this system becomes impracticable in the current conjuncture due to the lack of companies offering this service and the difficulty in obtaining information in the region.

The photovoltaic power generation system uses sunlight for electricity production using panels for the conversion. Growing environmental concern has accelerated the search for renewable energy sources. In Brazil, the use of photovoltaic energy has stood out with the standardization of distributed micro and mini-generation. According to data from the Brazilian Electricity Regulatory Agency (ANEEL), the number of installations surpassed the 20 thousand units in January 2018.

The advance of policies to encourage the use of renewable energy aims to diversify the Brazilian energy matrix, predominantly supplied by hydroelectric p. The Brazilian Council of Fiscal Policy (CONFAZ) approved ICMS Agreement 16/2015 of April 22, 2015, authorizing states to grant the exemption for transactions of internal circulation of electricity that are billed in the energy compensation system. Therefore, the states that adhered to this agreement started to charge the value-added tax on sales and services (ICMS) only with respect to the difference between the energy consumed and that generated (ANEEL, 2016).

The search for renewable energy sources and the need for diversification of the Brazilian energy matrix are current problems of the society as a whole. Low environmental impact, diversification of energy sources, low loads in the grid, and low losses are among the benefits provided by the distributed generation system. In Brazil, despite the enormous potential of photovoltaic generation and the growing number of installed units, the use of this technology has not been significant yet, representing only 0.1% of the total power used (DANTAS; POMPERMAYER, 2018). However, in addition to the environmental factor, the increase in electricity tariff in recent years has intensified the search for systems that reduce the expenses generated by energy consumption.

With this scenario, the attention arises in understanding how advantageous photovoltaic energy could be when implemented in an agribusiness company that produces pig and distributes pork meat. The present study analyzes the economic and financial viability of a photovoltaic power generation project in a small pork operation, which consists of the pig farming and the pork meat distributor. Production has 60 sows, and the reared pigs go through growth and fattening phases, which last 150 days. The high energy consumption in the rural property is related to the distributor activities due to the refrigeration equipment and freezing of products for storage and distribution. Thus, the reduction of energy costs has a high impact on business.

The analysis will be developed considering the current size of the property and assessing the impact of a distribution expansion project, in which additional refrigeration equipment that requires higher energy consumption will be purchased. Specific investment project analysis techniques, such as net present value (NPV) and internal rate of return (IRR), are applied to verify whether the photovoltaic implementation project could generate return to the property. In addition, it is also considered that financial decisions are usually not made in an environment of total certainty regarding the expected results. Therefore, these forward-looking decisions must be analyzed by introducing an uncertainty variable, using a Monte Carlo simulation procedure. Risk analysis in high-cost projects aiming at cost reduction and increased profitability is essential as it broadens the amount of information for the decision-making process.

The paper also intends to understand the benefits related to the photovoltaic generation system, which, although not yet significant in the Brazilian energy matrix, presents the possibility of reducing electricity costs. The updating of ANEEL regulations and incentives from federal and state spheres have driven growth and the demand for this kind of system, these initiatives are, for instance, distributed generation, increased validity of energy credits, and ICMS exemption in some Brazilian states (DANTAS; POMPERMAYER, 2018). For robustness, it was explored how the expansion of this business and the consequent increase in energy consumption would interfere with the economic viability of the project. Highlighting the return on investment in the project, this study seeks to analyze the impact of the raise in electricity tariff and the likelihood of positive return on investment based on energy tariff and minimum acceptable rate of return (MARR) simulations.

This study is structured as follows: Section 2 presents a brief review of economic viability studies of photovoltaic energy in Brazil; and Section 3 presents the applied methodology, in which the tools, incremental cash flow construction, and simulation procedure are described. The results are presented in Section 4. Finally, Section 5 describes the conclusions of the study.

2. Literature Review

The conversion of solar energy into electricity happens from the transformation of photons present in sunlight. This process happens in photovoltaic cells, which are mostly silicon plates. The use of energy from the sun brings electrical, environmental, and socioeconomic benefits. Electrical benefits consist of the diversification of the Brazilian energy matrix and increased security of supply. Environmentally, the use of this type of energy allows low greenhouse gas emissions and no environmental degradation where it is installed. Finally, socioeconomically, this system increases revenue and investment, contributing to the generation of local jobs (NASCIMENTO, 2017).

In order to enable distributed power generation, ANEEL opened in 2010 a public consultation aiming to discuss the legal provisions for connection and generation of small size electricity in the existing distribution grid (ANEEL, 2014). In 2012, the normative resolution REN no. 482 of April 17, 2012, was created to regulate the distributed micro and mini-generation systems, connected to the electricity distribution systems and electricity compensation system (ANEEL, 2014). The regulation establishes that micro and mini-distributed generation are characterized by the production of electricity, connected to the distribution grid through consumer units in small generating plants, using renewable sources or qualified cogeneration.

The biggest obstacle in distributed generation is the investment recovery. Resources required in the initial system installation are responsible for the non-popularization of the photovoltaic system among households. Project installation cost is high, but according to Shayani, Oliveira, and Camargo (2006), “the photovoltaic system tends to become economically competitive in the short term with the annual reduction in the cost of solar systems and valuation of environmental and social costs of centralized generation.” Dantas and Pompemayer (2018) studied the economic viability of grid-connected photovoltaic power use in Brazil based on ANEEL data and considering the cost of energy supplied and local solar incidence and concluded that the cost of photovoltaic power generation is lower than the cost of energy supplied by distributors in the residential tariff (with taxes) in all Brazilian municipalities. Also, the installation of a photovoltaic energy system allows savings in the energy bill, as it guarantees the exchange of excess energy produced by the system for credits in kilowatt-hour (kWh), resulting in low expenses with electricity (JÚNIOR et al., 2018).

Rossi and Martins (2018) assessed the implementation of a photovoltaic power generation system to meet the partial electricity demand of a plastic injection company and identified the project viability in the cash payment modality using NPV. NPV was also simulated using rates and policies of a financing program called Desenvolve SP (São Paulo Development Agency), which offers an interest rate of 5.2957% per annum, with a maximum payment term of 120 months and a grace period of up to 24 months. This option proved to be viable and was the most advantageous alternative than the cash payment.

Gomes and Camioto (2016) analyzed the economic viability of implementing photovoltaic power generation systems in residences in the municipality of Uberaba, MG, Brazil. The results showed that the project would be viable only when energy was demanded during the red tariff period. In this case, the used MARR, i.e., a SELIC (Special System for Settlement and Custody) rate of 14.15% per annum, made the other tariff flags not viable. Therefore, the project could have become viable across all tariff flags with a stable economy or other MARR.

Some papers also highlight the importance of understanding how future uncertainties affect project profitability. For instance, Figueiredo (2006) analyzed the production of broiler chickens in the microregion of Viçosa, MG, Brazil, and he observed that when risks inherent to the activity, such as chicken price and gas costs were included with the Monte Carlo simulation, the venture was susceptible to risks despite the financial indicators used for investment appraisal showing the economic viability of the project. It may also present losses if management failures or epidemics occur, which would lead to a drop in selling price and zero profitability.

Ponciano et al. (2004) analyzed the economic viability of fruit production in northern Rio de Janeiro, Brazil, and could identify the risk present in each crop using the Monte Carlo method based on selling price and MARR variation. In this case, guava and mango crops presented more risk to the producer, as the instability in selling price and labor costs generated a high probability of negative results.

3. Methodology

To conduct the analysis, we first collected information about the cost of electric energy in the rural property and the total resources needed to purchase photovoltaic energy equipment. Information on the electricity consumption of the property was collected from January 2017 to January 2019 to elaborate incremental cash flow for this project. Based on this data, a company specialized in solar energy generation equipment, located in the city of Leme, SP, Brazil, was contacted to estimate the budget value of the initial investment. The budget presented the total amount of R$ 78,200.00, with an average monthly production of 2230 kWh using the equipment listed below:

- 54 AS-6P-340 (340 Wp) INMETRO Class A photovoltaic modules.
- 1 assembly of aluminum frame for attachment to plant-type soil.
- 1 SMA SUNNY TRIPOWER 15000 inverter.
- 1 20 kVA 380/220 Vac transformer.
- Area required for installation: 115 m^2.

The company estimated the equipment lifecycle at thirty years in its budget, but a 15-year horizon was set for calculating the economic viability of the project. This time was estimated according to the inverter lifecycle, which is about ten years, but it may reach 15 years or more, depending on environmental conditions and the occurrence of atmospheric discharges, according to the manufacturer's information.

With the financial amount needed to implement the investment, it was estimated how much cash flow by year the rural property may save with the implementation of a photovoltaic system. The incremental cash flow was obtained by multiplying the annual consumption by energy tariff, implying that the higher the energy tariff is, the higher the incremental cash flow. Therefore, we treat the energy tariff as a variable with a high degree of uncertainty. Due to this, three scenarios were constructed based on the tariff behavior: (1) pessimistic, in which the tariff value is expected to decrease over the years; (2) realistic, which is the current tariff value; and (3) optimistic, in which the tariff increases. The probabilities of each scenario were estimated using historical information of the energy tariff charged by the power utility from April 2014 to March 2019. The sample was split among increase, decrease, and no change of the tariff over the available months and calculated the probability by relative frequency.

In addition to analyzing the viability of the photovoltaic system in the rural property, an additional test was conducted to check how it could be affected by raises in electricity demand due to an expansion in the productive capacity. In this simulation, we assume that increased production will require the purchase of one more refrigeration equipment with similar features of the current equipment in the property.

The economic and financial viability analysis of the project under study was carried out using the main analysis techniques of capital budget proposed by the literature. The first is the net present value (NPV), which is a tool that enables the calculation of the present value of future cash flows, discounted by the minimum rate of return required by the owners, i.e, the minimum acceptable rate of return (MARR). When NPV results in a positive value, we can infer that the investment project has a positive return and thus, it generates value for the company and consequently for its owners (CASAROTTO FILHO; KOPITTKE, 2010). The following expression defines NPV:

$$NPV = -I + \sum_{t=1}^{n} \frac{CF_t}{(1+K)^t} \tag{1}$$

where t is the time, CF_t is the cash flow, I is the initial investment, and K is the cost of capital. Besides, according to Ferreira (2009, p. 59), NPV "is based, as its name implies, on the updating of cash flows representing operating revenues, costs, and profits for a certain planning horizon, using as a discount rate, the minimum acceptable rate of return."

The second procedure to investigate whether an investment project should be implemented is the internal rate of return (IRR). This method specifies the rate of return that equates the initial investment, i.e the costs of project implementation at date zero, with the other incremental cash inflows that will occur over the life of the project. According to Samanez (2009, p. 37), IRR is a hypothetical rate that nullifies NPV, i.e., is the *K* value that satisfies the following equation below. Therefore, when the internal rate of return is larger than MARR, then the investment project can be accepted and implemented.

$$\sum_{t=1}^{n} \frac{CF_t}{(1+K)^t} = I \qquad (2)$$

Although NPV and IRR are robust techniques to analyze the viability of an investment project, they assume that researchers have the complete domain of all variables included in the calculation of the incremental cash flow and the initial investment, as well as the minimum accepted rate of return. In this sense, we conducted an additional test to understand how the net return of the project can be affected by changes in the energy tariff and in the minimum acceptable rate of return, using Monte Carlo simulation. This technique allows us to simulate thousands of possible scenarios, providing results of approximate probability distributions of the studied variables. Random values are used in the input data, subject to uncertainty, following distinct random distributions The frequency at which a given event occurs tends to be close to the probability of its occurrence when applied and repeated in various scenarios from the generation of random numbers.

4. Results and Discussion

4.1. The return of the implementation of photovoltaic energy system

As mentioned above, the incremental cash flow is obtained by multiplying the rural property's annual electricity consumption by the annual tariff charged by the energy distributor. As the energy tariff is R$ 0.46⁄kW and the consumption is 2100 kW⁄month, we find that the pig operation could save the amount of R$ 11,592.00 by year in the production process with the implementation of the photovoltaic system. However, to understand whether - and how much - this investment is profitable, we applied the NPV and IRR techniques and considered the current SELIC rate of 6.5% per annum as the minimum acceptable rate of return (MARR). The results are summarized in table 1:

Table 1: Net present value and internal rate of return

Period	Minimum acceptable rate of return	Investment	Annual cash flow	NPV	IRR
15 years	6.5% per annum	R$78.200,00	R$11,592.00	R$ 30,795.74	12%

Source: the authors.

The net present value was R$30,795.74 positive and the internal rate of return of 12%, indicating that the project generates value for the rural property, minimizing the energy cost and increasing the profitability of the swine business.

4.2. The impact of changes in the electric energy tariff

Since the incremental cash flow depends on the tariff charged by the energy company, an additional test was conducted to understand how increases and decreases in the energy tariff can affect the results. Figure 1 shows the behavior of the tariffs charged from April 2014 to March 2019.

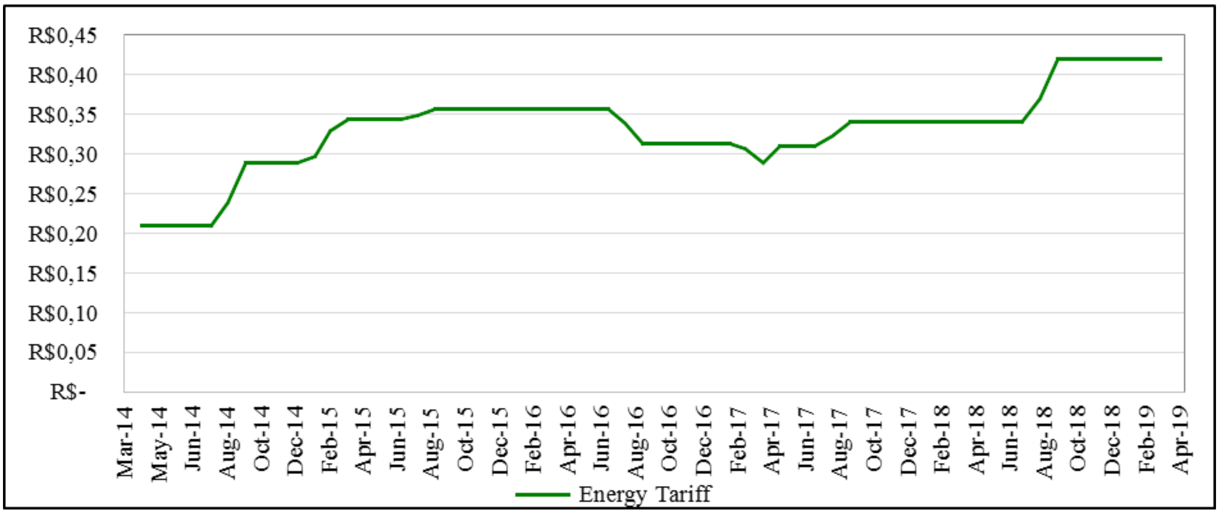

Figure 1: Energy tariff evolution from April 2014 to March 2019

Figure 1 presents a stable energy tariff most of the time, however, it contains moments of increases and reduction which allows us to split the sample among positive, negative, and no change values, and then, estimating the likelihood of each scenario by relative frequency. The results are displayed in table 2 and show that in 75% of the analyzed period there were no changes in electric tariff, while in 18% of increases and 7% of decreases in the costs of the energy.

Table 2: Probabilities for scenarios of increase, decrease, or no change in the energy tariff

Scenario	Frequency	Probability	Mean change
No change	45	75%	0
Positive change	11	18%	9%
Negative change	4	7%	-6%
Total	60	100%	–

Source: the authors.

After defining the probability of tariff change, we establish three possible scenarios in our analysis: (1) the expected scenario, in which there is no tariff change; (2) the optimistic scenario, with positive tariff change; and (3) the pessimistic scenario, with negative change in the energy tariff. Then, we recalculate the NPV and IRR for each one of these scenarios to obtain the expected NPV return by weighted average. Table 3 summarizes the results:

Table 3: Net present value for the expected, optimistic, and pessimistic scenarios

Scenario	Probability	Tariff change	Tariff	Investment	Cash flow	NPV	IRR
Expected	75%	0.00%	R$ 0.46	R$ 78,200.00	R$11,592.00	R$ 30,795.74	12%
Optimistic	18%	9.00%	R$ 0.50	R$ 78,200.00	R$12,600.00	R$ 40,273.63	14%
Pessimistic	7%	−6.00%	R$ 0.43	R$ 78,200.00	R$10,836.00	R$ 23,687.32	11%
					Expected NPV	R$ 31,585.56	

Source: the authors.

The expected scenario, with a 75% chance of occurrence, shows a positive return of R$ 30,795.74, with an internal rate of return of 12% per annum. Under the optimistic scenario conditions, in which there is an increase in the tariff imposed by the power utility, NPV is high, with a value of R$ 40,273.63 and IRR of 14%. An 18% probability was estimated for this scenario to occur. Finally, the pessimistic scenario, which has a 7% probability of becoming real, showed that the project tends to generate a positive return of R$ 23,687.32 and a return rate of 11%. Thus, the project analysis shows that despite changes in the scenarios, the investment project is economically viable under all conditions, signaling the absence of risk given the assumptions made. In other words, there is no risk of negative return under a minimum acceptable rate of return of 6.5% per annum, assuming an equipment lifecycle of 15 years.

4.3. Addition test: an increase in the amount of demanded energy

In the following test, it was considered an expansion in the swine business after one year of the implementation of the photovoltaic system. In this situation, the pig producer plans to buy one more refrigeration equipment with the same features as the current equipment at the property, increasing the demanded energy by 750 kW/month. The calculation of incremental cash flows under this situation considered the difference between the average production of the photovoltaic system of 2230 kW/month and the average consumption of 2100 kW/month, which generates a surplus of 130 kW/month, as shown in Table 4.

Table 4: Energy surplus produced by the system

System production (kW/month)	Consumption (kW/month)	Production surplus (kW/month)
2230	2100	130

Source: the authors.

The difference between the increased consumption (750 kW/ month) and system surplus (130 kW/month) was 620 kW/month. This value was multiplied by the tariff of R$ 0.46 and discounted from the cash flow used in the first analysis (without expansion). The results shown in Table 5 evidence how the increase in energy demand affects the estimated return on investment. The NPV value for this simulation is R$ 1,829.56 while the internal rate of returns is 6,88%. It shows that the photovoltaic system in the rural property generates positive returns, even with an increase in electricity consumption.

Table 5: Net present value for demand increase from the second year

Period	Minimum acceptable rate of return	Investment	1st-year cash flow	2nd-year cash flow	NPV	IRR
15 years	6.5% per annum	R$ 78,200.00	R$ 11,592.00	R$ 8,169.60	R$ 1,829.56	6.88%

Source: the authors.

The analysis was also expanded to study the tariff and energy demand to understand the minimum tariff and maximum demand amount that result in a positive NPV value. The expression used for this calculation is described as follows:

$$\sum_{j=1}^{n} \frac{Annual\ tariff * Mean\ consumption}{(1+MARR)^{j}} = I_0 \tag{3}$$

where the annual tariff is equal to 12 times the monthly energy tariff, I_0 is the initial investment, and *j* is the period.

The value of the increase in demand that makes NPV zero was estimated from the energy tariff of R$ 0.46/kW and MARR of 6.5% per annum in the original scenario, without capacity expansion. The obtained result is 659 kW/month, which is the maximum limit for the project to be viable, while the minimum tariff for the project to be viable, considering the current consumption of 2100 kW/month, is R$ 0.33/month. Therefore, we can conclude that the implementation of the photovoltaic energy system will generate positive returns for the swine breeder as long as the energy consumption is less than 659kW/month and the electric energy cost imposed by the energy company is less than R$0.33/month.

4.4. Monte Carlo simulation results

The uncertainty in the net return of investment on a photovoltaic energy system is considered both on tariff and on the minimum acceptable rate of return. Using Monte Carlo simulation, the purpose of this analysis was to estimate the likelihood of a negative return on the photovoltaic power generation investment since it is subject to changes in the energy tariff made by the distribution company and MARR.

First the analysis investigated the changes in tariff value while other parameters were kept constant. Random sample with 10,000 observations was generated following a uniform probability distribution with values between 0 and 1 based on the mean and standard deviation of the energy tariff practiced by the power utility from April 2014 to March 2019. Panel A of Table 6 shows the descriptive statistics of the sample used for the simulation of NPV with tariff variation.

Table 6: Uncertainty on energy tariff

Panel A: Descriptive statistic for tariff values				
Mean	**Standard deviation**	**Minimum value**	**Maximum value**	**Samples**
R$ 0.35	0.04673	R$ 0.17	R$ 0.55	10,000

Panel B: NPV values for uncertainty of tariff values					
Mean	**Minimum**	**Maximum**	**Number of positive**	**Number of negative**	**Sample**

R$ 5,448.37	−R$ 35,762.99	R$ 53,082.97	6,883	3,117	10,000

Source: the authors.

On average, NPV showed a value of R$ 5,823.80, with a 31% probability of values being lower than zero. The maximum NPV value found was R$ 53,082.97 when the tariff assumes the value of R$ 0.55, while NPV reaches its minimum value of −R$ 35,762.99 when the tariff is R$ 0.17. Figure 2 shows the histogram of NPV values obtained by simulating energy tariffs.

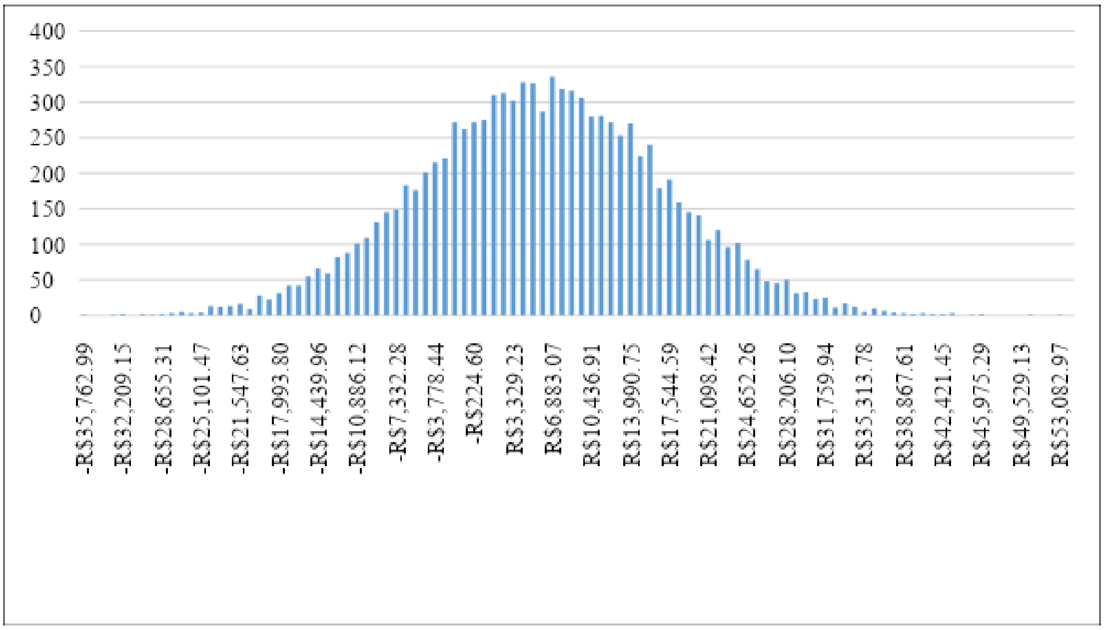

Figure 2: Simulation of tariff variation
Source: the authors.

The second simulation is related to the minimum acceptable rate of return (MARR) used in the NPV calculation. To conduct the tests, we considered the range between 2.5 and 16.5%, analyzed by subintervals with an amplitude of 2 percentage points. This minimum value of 2.5% was established based on the annual interest rate for the Pronaf ECO financing program, which promotes investment in the implementation, utilization, recovery, or adoption of environmental and forestry technologies (BANCO DO BRASIL, 2019). The probabilities of positive and negative returns of the project were analyzed from this information, simulating 10,000 values for MARR according to a triangular probability distribution. The choice of this probability distribution is due to the nature of the minimum acceptable rate of return, which cannot assume negative values. Thus, the simulation of the triangular probability distribution was constructed from the mean of two random variables with a uniform probability distribution that has values between 0 and 1. Finally, the estimated MARR was obtained by the following equation:

$$MARR_{estimated} = \mu + \rho\sigma$$

in which μ is the mean, σ is the standard deviation for the subinterval with an amplitude of 2 percentage points in the range from 2.5 to 16.5% per annum, and ρ is the probability derived from the mean of both uniform distributions. NPV was recalculated for each estimated MARR value, and the frequentist probability of negative return on the investment project was obtained. The variations were simulated in MARR ranges to understand the probability of negative return according to an increase in the return rate; they were requested by the owner of the pork business. As MARR represents the minimum percentage return expected by the owner to make the investment project viable, simulating this value is essential for understanding which is the maximum return that the project can present given a MARR variation. The main results are shown in Table 7:

Table 7: Results for the simulation of the minimum acceptable rate of return

MARR range (%)	Positive NPV	Negative NPV	Probability of negative return	Mean NPV
2.5–4.5	10000	0	0%	R$ 23,849.63
4.5–6.5	10000	0	0%	R$ 15,983.37
6.5–8.5	10000	0	0%	R$ 9,525.42
8.5–10.5	10000	0	0%	R$ 4,177.10
10.5–12.5	4869	5311	53%	−R$ 289.71
12.5–14.5	0	10000	100%	−R$ 4,050.57
14.5–16.5	0	10000	100%	−R$ 7,241.70

Source: the authors.

Considering the 10,000 observations simulated in each range of MARR, we find that the investment in a photovoltaic system in a pig operation remains totally profitable until the minimum acceptable rate of return of 10,5%. However, as the MARR range increases, the likelihood of profitable investment decreases. We find that in the 10,5% to 12,5% interval, 53% of observations have a negative NPV, while above 12,5% there is no evidence of positive return.

5. Conclusion

Incentive policies for the use of photovoltaic energy systems, as well as technological advances and the increase in electricity tariff, make this type of system attractive for agribusiness. Environmental benefits, such as cleaner energy production without greenhouse gas emissions and environmentally friendly installation, contribute to the sustainable development of society in the short and long term.

In this paper, several tests suggested positive returns for the implementation of a photovoltaic energy system in an agribusiness operation consisting in pig production and pork distribution in a countryside city in the State of São Paulo. The net present value for the expected scenario had a value of R$ 30,795.74, considering no tariff changes over the years. Scenarios with positive and negative changes in energy tariff also presented a positive net present value, with values of R$ 40,273.63 for the optimistic scenario, with an 18% probability of occurrence, and R$ 23,687.32 for the pessimistic scenario, with 7% probability of occurrence. Likewise it was investigated how the viability of the investment project may be affected by the refrigeration capacity expansion and consequent increase in energy demand, and it was found to have a net positive present value. Therefore, it is recommended that the farmer consider the implementation of the photovoltaic power generation system even after the expansion because the demand would be absorbed by the production of a system sized to meet the new consumption.

In sum, the main contribution of this case study consists in the support for decision-making by farmers in photovoltaic energy investments in rural properties that are highly dependent on electricity, contributing to more sustainable electrical, environmental and socioeconomic production. In addition to the NPV and IRR calculations, a Monte Carlo simulation was performed thus the farmers can analyze the risks and returns in different presented scenarios. The simulations suggest only positive values of NPV if the minimum acceptable rate of return is lower than 12.5%, so the farmer should avoid the implementation of a photovoltaic energy system if they expect a rate of return above this percentage.

Furthermore there is also a contribution to the development of public policies and government programs, since the higher the electricity tariff imposed by the energy utility, the more profitable the investment in a photovoltaic system tends to be. Therefore, the paper contributes both to the improvement of production units management and to the incentive of public policies and government programs that support investment in sustainability actions. These also generate economic growth of the operation and, consequently, more jobs and greater economic activity in the region. For future research, it is suggested to apply similar methodology in properties with other productive systems and different institutional arrangements from the present case study.

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