Translated from Portuguese to English - www.onlinedoctranslator.com
...ific Journal O Saber.
ISSN: 2675-9128. Sao Paulo-SP.

Year III, v.3, ed. 1, Jan./Jul. 2023. DOI: 10.51473/ed.al.v3i1.593 | submission: 07/17/2023 | accepted: 07/18/2023 | publication: 07/25/2023

TECHNICAL-ECONOMIC FEASIBILITY STUDY FOR INSERTION OF PHOTOVOLTAIC SYSTEMS AND ENERGY STORAGE IN A BRAZILIAN INDUSTRY[1]

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Summary. *This work discusses a methodological alternative for studying the reduction of the cost of electrical energy in a company in the Brazilian industrial sector based on a technical-economic feasibility analysis, which depends on factors such as component costs, legislation and technological advances. Recent studies show that technical-economic analysis has become increasingly favorable for the use of renewable energy, especially for residential consumers, but that there are still challenges to be overcome in the case of storage scenarios. The study analyzed the technical-economic feasibility of installing a hybrid electrical energy generation system, consisting of photovoltaic panels and battery storage, in a pharmaceutical medical device industry. Using simulation in the Homer Pro software, the company's current contract on the free market was compared with other concessionary tariffs, and it was verified that the current contract is less favorable for the installation of the alternative system due to the cost of energy being lower than the tariff of the distributor. From the results, the most viable option was identified as being a hybrid system composed of the electrical grid with a current contract with the addition of 3,200 kW of installed photovoltaic energy and current converter, and indicated that the system is viable both technically and economically, without the storage system installation. However, the simple payback period of close to 8 years can be considered long, which can make its implementation difficult in practice depending on each company's policies. The study suggests, from testing hypotheses based on the 'what if' condition through software sensitivity analysis, that with the cheaper photovoltaic panel technologies, as well as the increase in their efficiency and the variability of the price of electricity tariffs, energy, the implementation of distributed microgeneration in Brazilian industries can be better enabled.*

Key words: *Photovoltaic generation, Energy storage, Binomial pricing.*

1. INTRODUCTION

In recent years, more and more studies, developments and discussions have been observed around the search for (alternative) ways to reduce the cost of electrical energy (LIU et al., 2019). Currently, faced with a possible scenario of growth in demand, the search for solutions that allow guaranteeing the supply of electricity has become one of the focuses of large companies. This demand to guarantee supply can include (and does include) generation systems that use fossil fuels, but there is a marked movement to avoid fossil fuels and use systems based on energy generation from renewable sources (YANG; SUN, 2019) . In this sense, this trend must be compatible with companies' quest to become more efficient, more competitive and sustainable. In other words, the implementation of an energy generation system from renewable sources, with or without storage, must be technically and economically viable. This technical-economic viability depends on several factors and scenarios.

In scenarios where storage (direct energy injection) is not used, in addition to the costs of photovoltaic panels, inverters and other components, legislation, which determines the rules for this application, can have an important impact on economic viability. All of these factors have a dynamic character and require updates to feasibility studies, for example, on January 6, 2022, Law No. 14,300/2022 was published, which establishes the Legal Framework for Microgeneration and Distributed Minigeneration of Energy, the Energy Compensation System Electric Energy (SCEE) and the Social Renewable Energy Program (PERS) (BRAZIL, 2022) which has a direct impact on these feasibility studies. At the same time, in scenarios that include photovoltaic generation systems with energy storage, in addition to the legislation and costs of the components already mentioned, advances in storage technologies and price drops due to gains in production volume must be considered.

Among all the technologies used for energy storage linked to the use of renewable energy sources, batteries stand out for their modularity and ability to present relatively simple solutions for demands from a few kW/kWh to cases of hundreds of MW/MWh (ENFORMER , 2022). For this which is why battery-based energy storage is currently one of the most used

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(SANDIA, 2022). Among all available battery technologies, the most used for energy storage are those already considered traditional lithium-ion batteries and lead-acid batteries (KAMIVA, 2021). Other battery technologies that are also used, but on a smaller scale, are flow batteries and lead-carbon batteries (known as advanced lead-acid batteries) (BOWEN et al., 2021).

This research provides a detailed view of the possibilities for technical-financial gains from reducing the electrical energy consumed from the dealership's network throughout the year, as well as evaluating the energy efficiency potential that can be obtained from the company's global diagnosis versus to the solution presented, including possible future feasibility scenarios.

two.**BIBLIGRAPHIC STUDY**

Industrial plants are made up of different equipment with different electrical energy consumption and each one operates with different regime characteristics. The energy consumption profile of a manufacturing plant is given by looking at the overall system of all its equipment combined. Some of these may operate in non-uniform regimes, with daily or hourly intermittence, depending on production planning. Due to all these possibilities, electrical energy demands are constantly changing with a strong correlation between the power consumed and the volumes produced in the industrial process. The inherent consumption profile of industrial processes has been studied in several factories, seeking to optimize and reduce costs to increase operational efficiency and gain in competitiveness (MACHALEK; POWELL, 2019).

From a demand profile (power in operation) it is possible to study and design electrical energy generation systems to meet such demand. One of the energy generation technology options are photovoltaic panels that require the appropriate dimensioning of the electrical energy generation capacity and solar irradiation data in the geographical position in which the system is intended to be installed.

Photovoltaic systems have some limitations depending on the climatic conditions of the region where they will be applied, in addition to being an inherently intermittent energy generation system. However, by installing an energy storage system combined with this type of generation, an appropriate model can be obtained to mitigate this intermittency. Due to the type of material and technologies applied, the costs of photovoltaic energy generation systems are still relatively high, which limits their popularization and dissemination. However, in order to promote greater understanding and visualize the benefits of this type of system, it is necessary to study their feasibility and efficiency in economic terms for each application (YANG; SUN, 2019).

Fu and Remo (2018) suggest models and scenarios to ensure the best performance and lowest cost. One of the scenarios refers to the installation of a photovoltaic system combined with an energy storage system connected to the utility grid and the other scenario deals only with an individual energy storage system using lithium-ion technology batteries connected to the utility grid.

Tahir et al (2021) present a study on the development and optimization of an integrated hybrid system for energy generation, based on simulation in the HOMERPRO software, to supply energy to a rural area. The authors explain that a hybrid system can be composed of two or more energy generation and/or storage systems. For a more accurate analysis of feasibility, simulations were carried out with different scenarios using the HOMER software, which models and simulates different conditions to define the best power and storage system option, given a load profile.

Tahir et al. (2021), in their research, considered the impact of the energy storage system and concluded that one of the biggest challenges for this system is the size and space occupied, since these are still large systems if one intends to store a satisfactory amount of energy. energy. An energy storage system can be used in two ways, one to store the energy left over from generation while demand is lower than supply and the second is to compensate for the intermittency of renewable generation, as is the case with photovoltaic panels and hydro kinetic turbines.

In the sensitivity analysis for the system already identified as being the best, it is possible to evaluate the impact of some changes in parameters such as the intermittency of the renewable energy source, variations in load demand, solar incidence, etc. (TAHIR et al., 2021).

Tahir and collaborators (2021) conclude by concluding that after several simulations based on different scenarios and strategies carried out with the HOMER software and subsequently analyzed, the optimized hybrid system solution includes 40 kW installed in photovoltaic energy capacity, 25 kW installed for generation from a biomass generator and two hydrokinetic turbines, all integrated into the network to manage demand according to need. This system met 94% of the annual demand in the small town in Pakistan, from where the study was carried out.

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ZHU and collaborators, (2018) also present their conclusion with the statement that the application of energy storage systems in places where there is a dynamic variation in the electricity tariff can generate a significant gain, when the combined application of different methods, depending on the best condition at the time and cost. This can be applied strategically in the implementation of similar systems, as more and more energy price variations have been observed due to the impacts of external factors.

Regarding battery technologies, Zubi et.al (2018) conclude that of all these, the most successful in terms of efficiency is lithium ion, considered the most promising for such an application, because lithium is non-toxic and has a low density. and is highly electropositive. Therefore, according to the author, other metals or electrical energy storage options cannot compete with lithium. In the case of the present work, this does not apply due to the fact that lithium-ion batteries are imported (making the logistics of maintaining these systems, replacing parts, availability of spares on the market, etc. as already mentioned) and their high cost compared to lead-acid battery technology available on the national market.

In relation to the energy generation system using photovoltaic panels, there is a limitation of available physical space in addition to economic factors. The most common physical limitations are the availability of roof area for installing the panels, and depending on the case, this limitation can result in a low economic return, making the project unfeasible. Therefore, to have a complete view of the technical and financial analysis, the annual expenses with electricity must first be analyzed, which could become the project's gain. In fact, there is a direct correlation between the potential annual gains versus the total nominal power of photovoltaic panels.

Additionally, when all the energy produced is consumed, there is compensation for the energy acquired from the grid, so the annual gains are given by the cost of the energy purchased, including all fees, divided by the number of energy units consumed by the load (R$/kWh). Regarding the return analysis for the sale of produced/stored energy, this refers to the gains resulting from the sale (or compensation) of energy injected into the grid (KOSKELA et.al, 2019).

Energy storage systems are more common for applications in the option of cheaper energy in certain situations, for example, in cases of load variation, during peak periods. For example, charging the storage system at times when the cost of energy is cheaper and discharging it when the cost is higher. These systems are used in different niches or scenarios with the main objective of reducing the cost of energy for industrial operation or domestic consumption. The expectation is that the costs of these technologies will increasingly reduce in the future, which would facilitate the dissemination of the technology. Another primary application of these systems is at peak times, where the cost of energy from the concessionaire's network increases considerably. The battery energy storage system can either be charged directly by the grid at off-peak times, or also by some other generating source, for example, by renewable energy sources, using photovoltaic panels, wind turbines, among others (VENKATARAMAN et .al, 2018).

When talking about real applications of such technologies, to find an optimal solution in technical and economic terms, it is important to consider the entire context of the installation, including energy supply, costs, rates, load demand and available space, to then evaluate the impact of a potential project in this regard. All factors must be taken into account to obtain the best economic analysis, such as subsidies, reduction of transmission losses, gains from postponing network expansions and reducing impacts caused to the environment through the use of renewable electrical energy generation. at the place of consumption. Therefore, economic evaluation studies must include the cost of installing the system to harness renewable energy and its maintenance, possible exchanges and any other costs arising from its operation over time (LIU et.al, 2020).

Despite the studies found and analyzed in relation to the installation of hybrid generation and storage systems, the relevance and contribution of this study are centered on the analysis of the application in a Brazilian industry based on a tariff model specific to the country and state where the company studied. is installed. Given that many of the studies found are focused on countries abroad, few address the specificity of Brazil, and only a few works were found on the application of the Homer Pro software for analyzes aimed at remote regions, rural environments and commercial installations. Therefore, this work brings this type of analysis closer to the national industrial segment considering its dual pricing based on a case study with real data from a local industry.

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3.MATERIALS AND METHOD

3.1 Materials

The following materials were used:

The)*Software*for capturing consumption data: CCK Manager

- Application for CCK System Management.
    i. Version 8.18.12.1.
    ii. CCK Automações Ltda.

B)*Software*modeling and simulation: HOMER Pro®

- Version 3.147880.21077 (2017)

3.2 Method

The method used in the development of this work was computer simulation for economic-financial viability analysis applied to a Case Study, where the main tool was the Homer Pro software based on data collected from the Pharmaceutical company, the object of the study. All stages of this can be observed in the following steps:

Step 1 consisted of collecting energy consumption data (kWh), every 15 minutes, for the year 2019 using CCK® software. Demand was calculated based on consumption data (kWh), with the ratio of 15-minute consumption to the fraction of time (0.25 hours) to obtain the kW, this is because existing demand data is on a daily scale, what prevents obtaining the hour-by-hour profile;

In step 2, the current contract and its characteristics were studied, such as type of tariff, costs, contracted limits, fines, duration and others;

In step 3, a study of existing components on the market was carried out regarding potential technologies to be applied, their costs and operational characteristics;

In step 4, the area available for installing photovoltaic panels was analyzed;

Step 5 was to define the simulations: 3 simulations in real conditions of energy prices and technologies, varying only the contract characteristics;

In step 6, the simulations are presented considering the A4 blue contract in Mercado Livre, A4 blue from the Copel Distribuidora dealership and A4 green from the Copel Distribuidora dealership;

In step 7, the sensitivity analysis simulation was carried out with the extrapolated parameters to identify their impact on the final result of the study and thus determine their stability (in relation to the evaluated parameters);

Step 8 consisted of analyzing the results and discussing the simulations;

Finally, in step 9, the conclusions were presented.

4.CASE STUDY

The object of the present study is a medium-sized manufacturing plant, a branch of an American multinational pharmaceutical company producing large medical devices, located in the industrial city of Curitiba in Paraná, Brazil.

This case study aims to gather information that can be used to create an executive summary that can be used as part of a justification for a real project to install a photovoltaic power generation system, with or without a power supply system. electrical energy storage (based on batteries) for the company's energy management, aiming to reduce costs.

The main aim is to reduce energy costs during peak and off-peak times; but other scenarios were also simulated to identify the best configuration and determine its sensitivity to system components.

4.1 Contracts and their basic definitions

Fig. 1 presents the entire categorization of tariff modalities and details the particularities of each one. Within the green and blue subdivisions, for high voltage group tariffs it is clear that demand and consumption tariffs are broken down.

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Figure 1 - Tariff types

Based on the aforementioned definitions and characterizations, Tab. 1 presents the contract parameters of the object of study of this dissertation, referring to the year 2022.

Table 1 - Contract parameters

Parameters	Contract
Voltage	13.8 KV
Hourly-seasonal demand (KW power) contracted	3500 KW (on tip); 3600 kW (off peak)
Contracted energy consumption (KWh)	1,620 MWh +/- 10% per month
Price of energy consumed (Copel - TUSD)	R$ 0.1231 per KWh
Price of energy consumed (Cemig Mercado Livre - TE)	R$ 0.1917 per KWh
Off-peak demand fare	R$ 12.7168 per KW
Demand fare at Ponta	R$ 26.8777 per KW
Group	Blue
Hourly rate	A4
Rush hours	From 6:01 pm to 9:00 pm

Although the blue tariff contract is currently in force, this study aims to present a simulation for the green tariff contract and analyze the differences, in practice, between the two tariff models. For this, data from Figs 2 and 3 were used, tariffs currently applied to group A4, within 2 different simulations regarding the tariff scheme.

Table 1 does not show different prices for kWh between the peak and off-peak periods due to the validity of the contract with the free market. In this way, the value of the kWh consumed is the same inside and outside the peak and is added and composed of the cost of the free market (Cemig) and the fee charged by the concessionaire for transmission (Copel).

It is important to clarify that the method used (simulations with the*software*Homer Pro) does not allow the addition of fines in case of exceeding the contracted limits for demand, that is, in the case of consumed demand is higher than contracted (3600 kW), the*software*does not consider the imposition of fines. What the*software*What it does is prevent energy consumption from the grid when the contracted values are exceeded. Furthermore, in the simulations, 3 contract levels were included, these being 4500 kW, 3600 kW and 3000 kW for the worst case off-peak. In the company's current contract, the fine for exceeding the contract values is the charging of double the price per contracted kW for each kW exceeded, both on and off peak.

Energy tariffs (TE) refer to the energy consumed, that is, the cost of the kWh used. The distribution system usage tariff (TUSD) is divided into 2, the consumption tariff, which refers to the kWh of energy, and the contracted demand tariff, which is related to the kW of power.

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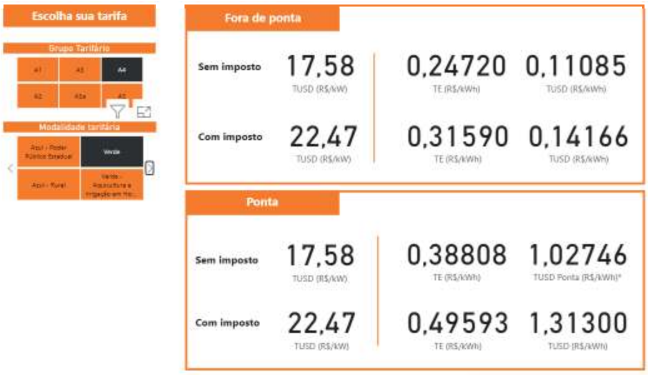

Figure 2 - Tariffs applied to the A4 Green contract

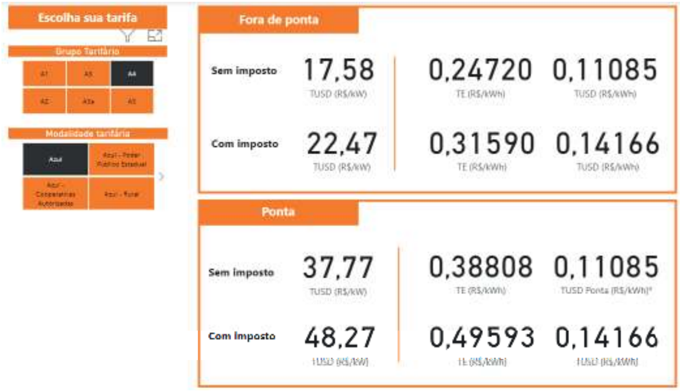

Figure 3 - Tariffs applied to the A4 Blue contract

Currently, the pharmaceutical company, the subject of this study, has an energy contract with the free market. In this way, it is part of a group of private companies without ties to the state's energy concessionaires, which guarantees it a lower energy price than that currently charged by the local concessionary company. Therefore, the tariffs presented in Fig. 3 do not correspond to the company's current situation. Therefore, for the blue A4 simulation of the free market, the current prices in force in the company's contract were used.

For the simulation of the Copel green and Copel blue A4 contract, the data from Figs 2 and 3 were used, simulating the captive consumer condition. It is important to point out that the tariff values used in the study were tax-free, since a large part of the taxes (ICMS) are recoverable in the case of the company studied in this work due to the benefit allowed by the government of the state of Paraná.

The binomial tariff condition, where you pay for demand and consumption, currently present in the company's contract, presents a percentage of the total amount paid in the monthly invoice on average of 26% for demand and 71% for consumption, with the difference referring to taxes and public lighting fees.

a) Project topology (HOMER PRO®)

Fig. 4 presents the project scheme that allows the *software* HOMER® perform optimized modeling simulations. Below it is possible to identify two lines, which represent the AC (alternating current) and DC (direct current) buses, between them we see a converter that makes the appropriate conversion of continuous, coming from the electrical energy storage system and the generation system by photovoltaic panels for direct current, which is consumed by the load.

As already mentioned above, the components on the right of the diagram represent the generation and storage system and on the left are the network, with an input signal to the system, indicating the energy flow, and the load with system output signal, indicating consumption.

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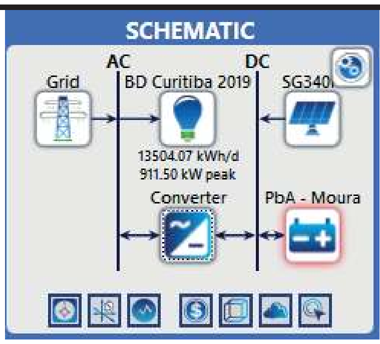

Figure 4 - Schematic topology of the project configuration

For each element inserted in the project, it is necessary to parameterize its component. These parameters need to follow the most realistic data possible so that the model can reflect the situation found in the factory under study and the possibility of installing these auxiliary elements with the success assumed by the simulation output, when applicable.

b) Network characteristics

The configuration was made based on real data from the company, and the characteristics of the current contract. Among the tariff options, scheduled tariffs were chosen as there are different tariffs depending on the consumption time, peak and off-peak, as shown in Table 2.

The item "*reliability*" within the network settings, refers to the reliability of the network and possible intermittences in the power supply. But as there is no known history of power outages in the network that powers the company, reliability was maintained at 100%.

c) Load and demand profile

To define the need for energy demanded by the system, the company's consumption history was used. This history is recorded in the company's energy management system, called CCK.

For the purpose of the study, data from records made in 2019 were used, as due to the variability of energy consumption during the pandemic (which changed the company's production rates), it was chosen to use pre-pandemic data, as they better represent the normal operation of the company.

d) Generation system: Photovoltaic system

Through the address of the company studied in this dissertation, it is possible to obtain solar irradiation data. This data is essential for the program to define the parameters for energy generation by photovoltaic panels. O*software*Homer uses the NASA database to present the annual irradiation profile. These data are average values for 22 years between 1983 and 2005 and are presented in KWh/m²/day.

For the present simulation, data from photovoltaic panels from the company OSDA were used (commercial panels available on the market, reference date of July 2022). I also highlight here the information on the use of scrap as part of the replacement value of the panels, this was extracted from the supplier's quote and demonstrates the complete management of the entire cycle of this type of product. These characteristics are presented in Tab. 2 and these were transferred to the simulation software.

Table 2 - Characteristics of the photovoltaic panel

Feature	Parameter
Manufacturer	OSDA
Model	ODA465-36V-MH
Power	465 +/- 3 Wp
Standard efficiency under test conditions	21.3%
Dimensions	2102 x 1040 x 35mm
Lifespan	25 years
Reduction coefficient	80%
Effect of temperature	- 0.35%/ºC
Nominal operating temperature	45ºC

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Replacement (with reuse of scrap)	65% of the acquisition value
Operation and maintenance (quote reference)	1% per year
Asphalt reflectance (PUTTONEN et. al, 2009)	20%
Reference value (NEOSOLAR, 2022)	R$ 1049.00 per panel

It is important to highlight that the sizing of installed KW is the result of the software's own optimizer, with limiting levels of 0 to 3,200 KW of installed power and that installation costs make up the value of the panel unit (estimated approximately 25% with gain from negotiation of scale). The upper limit (maximum installed capacity) was obtained from the limit of area available for installing the panels on the roof.

The area available for installing photovoltaic panels is limited to 14,000 m² (Eq.(5) and Eq.(6)). From this area value, and taking into account the dimensions of each installed panel, the maximum number of panels is determined.

$$n^{\circ}\ de\ painéis = \frac{área\ total\ disponível}{área\ do\ painel} \quad (5)$$

Source: The Author (2022).

on what:

is the number of panels that can be installed within the available area;

= this is the free area for installing the panels; =

occupation area of each panel in your installation.

$$limite\ máx\ instalado = n^{\circ}\ painéis \times potência\ painel \quad (6)$$

Source: The Author (2022).

on what:

is the maximum installed capacity (kWp);

is the number of panels that fit in the installation area.

e) Electrical energy storage system using batteries

As a reference for the SAEEB (Battery Electric Energy Storage System), a market battery was used with the characteristics and attributes described in Tab. 3. This item was parameterized as a unit in the simulation software library.

Table 3 - Battery unit characteristics

Feature	Parameter
Manufacturer	Moura
Model	Pb-Acid - Moura 12MS234
Power	2.8 kWh
Voltage	12V
Maximum capacity	234 Oh
Technology	Acid lead
Maximum temp. of operation	65°C
Minimum temp. of operation	- 10°C
Initial state of charge	100%
Minimum state of charge	80%
Degradation threshold	20%
Series Configuration	45 units (540 V)

For the simulation, market values (as of July 2022) were used for acquisition, replacement, maintenance and useful life costs, according to Table 4.

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Table 4 - Market attributes for battery model

Attribute	Value
Acquisition value (MINHACASASOLAR, 2022)	R$ 1349.00 per unit
Replacement per unit	60% of the acquisition value (reference from contacts with manufacturer MOURA)
Maintenance per unit	1% of the acquisition value (reference from contacts with manufacturer MOURA)

As with panels, the use of scrap in the replacement cost is a great ally for these systems and demonstrates complete management of the material's life cycle, bringing more sustainability to its application.

f) Direct current (DC) to alternating current (AC) conversion unit

In addition to the batteries and photovoltaic panels, it is necessary to include the DC/AC current converter in the simulation, which allows the direct current bus to be interconnected with the alternating current bus. The photovoltaic energy generation system, as well as the battery storage system, operate on direct current, however the load is powered by alternating current. To include the converter, it is necessary to provide the *software*its operational information. The data from the converter used in the simulation were extracted from a commercially available product (on the national market, as of July 2022) and are presented in Tab. 5.

Table 5 - Characteristics of the frequency converter (current converter)

Characteristics	Parameter
Capacity	123KW
Lifespan	10 years
Efficiency (converter input)	98%
Relative capacity (depending on the operating regime)	100%
Efficiency (rectifier input)	98%
Acquisition value (MAGAZINELUIZA, 2022)	R$100,000.00
Unit replacement (reference in quote)	65% of the acquisition cost
Unit maintenance (reference in quote)	1% of acquisition (annual)

1.1 **Modeling**

The results of the simulations carried out with the aid of*software*Homer using the data entered for each element of the project. O*software*allows configuring simulations so that project elements can change some of their operational parameters, Tab. 6, within pre-established value ranges, adding or removing some elements, as defined in the sensitivity analysis. After completing the simulations (using all permitted combinations of parameter and component values), the results are presented in order to identify the best combination of components and sizing, always aiming for the lowest project cost (in addition to allowing the proposed solution to be compared with the current situation).

The main comparative parameter for choosing the best system configuration is the cost per unit of energy consumed (R$/KWh) by the load, but other information is also obtained as a result of the simulations, such as the cost of operation and maintenance over a period of time. the entire useful life of the system (O&M), net present value, cash flow, among others.

The economic viability analysis carried out by the*software*is based on the cost per unit of energy (R$/kWh) and the*payback*simple, the latter calculated based on the return on investment over time, to obtain, in how many years the invested value returns directly, without a discount rate. The best option (lowest operating cost of the load in terms of electrical energy in R$/kWh consumed) will be presented as the winning configuration, that is, classified in first position as the best system option to be installed with the lowest cost of operation.

a) Economic indices

The economic indices used in the simulations are: minimum attractiveness rate of 15% is a reference

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for investment in fixed income in Brazil, based on the current Selic rate (BANCO CENTRAL DO BRASIL, January 2023), the inflation (IBGE, 2023) considered was that of the last 12 months until November 2022, and the time of The project analyzed lasted 25 years.

b) Sensitivity

For the sensitivity analysis, different potentially viable values were assigned to the components chosen according to Table 6. The components present in the table were defined by the criterion of being the main variables of financial impact in the analysis of application of generation by photovoltaic panels and for storage of electrical energy by batteries. The potentially viable values for each component were chosen to highlight the potential impact of each one on energy costs in the simulated scenarios. The way to introduce these potentially viable values is through reference cost multiplier factors.

The economic indices considered in the sensitivity analysis were the same as those used in the simulation and presented in item a of this chapter, with the exception of the inflation index, which had two limit values added as per Table 6.

Table 6 - Factors and levels for sensitivity analysis

	Components considered in sensitivity								
Variations of level	Cost from the energy on the network (R$/ kWh)	Credit towards-thought on the network (kWh)	Multiply-pain in the ass to panels photovoltai-waistband	Multiply-cost pain of manual tension of photo panels voltaic	Multiply keeper of Cost of replacement of the panels photovoltai-waistband	Multiply-pain in the ass to Batteries	Multiply-cost pain maintenance tion Batteries	Multiply keeper of Cost of replacement of Batteries	Inflate dog Yearly
Value 1	0.3148	0	75%	50%	50%	10%	50%	50%	3%
Value 2	0.6256	3000	50%	0	0	1%	10%	10%	10%

c) Execution of simulations

Four simulations were carried out in total, three referring to the nominal values and parameters of the system with changes among them only to the contract tariffs (A4 green Copel, A4 blue Copel – Fig. 2 and 3 – and A4 blue Mercado Livre) and one of sensitivity, with variable limits for each component (Table 6), and the appropriate restrictions as in the case of the number of photovoltaic panels (0 to 3200 kW), allowing the software to optimize the system within these limits. These value variation ranges (example: cost of photovoltaic panels at 75% or 50%) presented in Tab. 6, were proposed to allow the*software* analyze the impact of these parameters on the economic viability result (and its sensitivity). It is important to highlight that for sensitivity, the base nominal values for component costs and their operation and maintenance costs were not considered, since the impact of these values are already present in the first simulations carried out with only nominal values.

5.**RESULTS**

The simulation results for the different contract characteristics are summarized in Table 7, with each system winning in the 3 simulations.

Table 7 - Comparative summary between scenarios

Contract					NPV	Operating Cost-dog	Capital initial	Cost of kWh	Payback Simple
A4 market blue Free	3200 kW	-	45000 kW/year	2051 kW	R$ 94 millions	R$ 8.38 million million/year	R$ 8.89 millions	BRL 0.367	7.6 years
A4 green Copel	3200 kW	-	45000 kW/year	2108 kW	R$ 129 millions	R$ 11.8 million million/year	R$ 8.93 millions	R$0.505	6.6 years
A4 blue Copel	3200 kW	-	45000 kW/year	2108 kW	R$ 114 millions	R$ 10.3 million million/year	R$ 8.93 millions	BRL 0.443	6.6 years

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It is observed that in all cases the same result is obtained, with the same winning system, in which the current contract is with the free market, plus the installation of a photovoltaic generation system with an installed capacity of 3,200 kW and a power converter. current with 2,051 kW capacity.

It is valid to add that among the contracts with direct tariffs from Copel Distribuição SA, the best system would be with a blue A4 contract. Another important point is that the*payback*observed in both Copel conditions is justified by the higher cost of energy and, therefore, greater gains when using photovoltaic generation.

4.2 Sensitivity analysis

The sensitivity analysis was carried out based on the value multipliers assigned to each component, again presented in Table 8.*software*Homer carried out various simulations with all possible combinations of parameterized values and sought the best configuration of components and values (best case for each component given its costs and operating conditions).

Table 8 - Factors and levels for sensitivity analysis

	Components considered in sensitivity								
Levels of components	Cost of energy on the network R$/kWh)	Credit towards-thought on the network (kWh)	Multiply- pain in the ass to panels photovol tai- waistband	Multiply- cost pain maintenance tion of parents- nees photovol- taicos	Multiply- pain in the ass sub- title of photo panels voltaic	Multiply- pain in the ass to Batteries	Multiply- cost pain maintenance tion Batteries	Multiply- pain in the ass sub- title of Batteries	Inflate dog Yearly
Value 1	0.3148	0	75%	50%	50%	10%	50%	50%	3%
Value 2	0.6256	3000	50%	0	0	1 %	10%	10%	10%

As output of the sensitivity simulation, the main configurations with the best operating cost (R$/kWh) are presented. Tab. 9 summarizes this result with the classification of configurations and the winning model.

Table 9 - Optimized sensitivity scenario

Classification					NPV	Operating Cost portion	Starting capital	Cost of kWh
1	3200 kW	-	45000 kW/year	2108 kW	R$ 129 millions	R$8.35 million/ year	R$5.32 million	BRL 0.345
two	3200 kW	450 units.	45000 kW/year	2152 kW	R$ 129 millions	R$ 8.34 million/ year	R$5.37 million	BRL 0.345
3	-	-	45000 kW/year	-	R$ 140 millions	R$9.45 million/ year	0	BRL 0.375
4	-	630 units.	45000 kW/year	28.5 kW	R$ 140 millions	R$9.45 million/ year	R$32 thousand	BRL 0.375

It should be noted that the winning configuration has the photovoltaic energy generation system, with an installed capacity of the maximum permitted limit of 3,200 kW due to the available area, the contracted network with 45,000 kW/year and the converter with a capacity of 2,108 kW; without using a battery storage system. Sensitivity analysis was applied to this winning configuration, allowing variations in values (parameterized by multiplier factors) in its components, which allows evaluating their impact on economic indicators.

The following graph, Fig. 5, presents the comparison of a configuration analyzed by sensitivity against the current contract system with the network at the blue A4 tariff with Mercado Livre, with its indicators economic and viability of the project.

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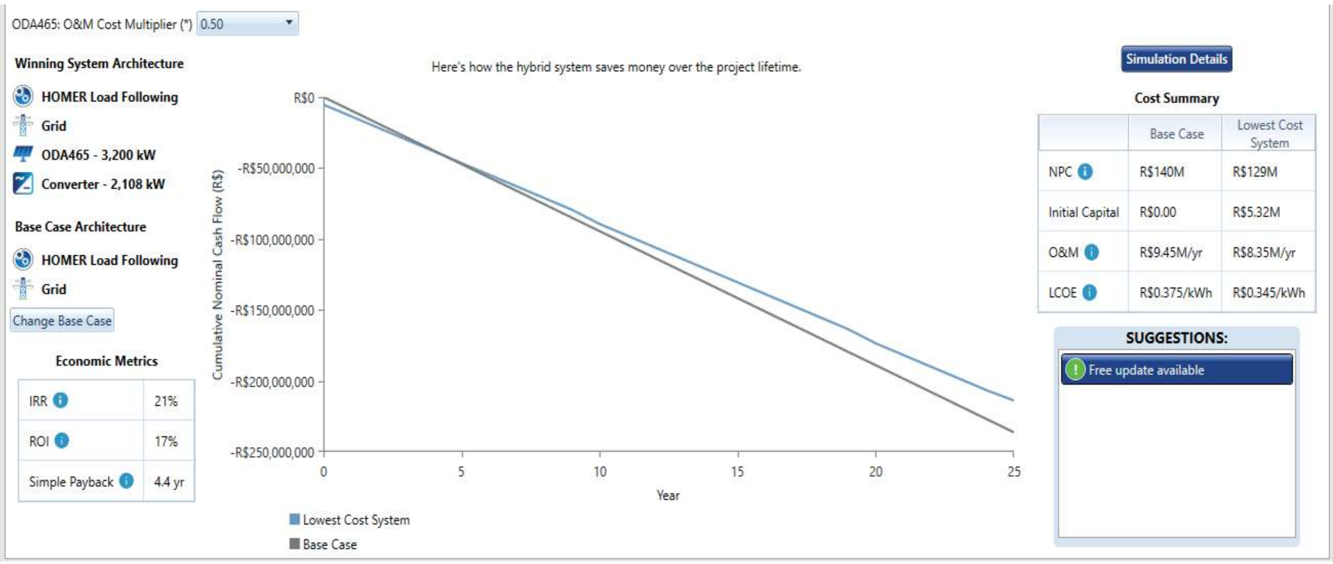

Figure 5 - Comparison result of winning configuration and current network system

It is observed that the indicators present a considerable difference in relation to the simulation with the nominal values, from Tab. 7, the total annual operating cost would be R$ 8.35 million in this condition and this leads to a very high internal rate of return. more attractive than 21%, with 17% return on investment and *payback* simple falling to 4.4 years.

The sensitivity values that were applied by the *software* for the system above are presented in Tab. 10.

Table 10 - Optimized configuration values

Winning system values considered in sensitivity								
Cost of energy on the network (R$/ kWh)	Credit towards-thought n network (kWh)	Multiply- pain in the ass to panels photovoltai- waistband	Multiplier of the cost of maintenance of the panels photovoltaics	Multiplier of the cost of replacement of the panels photovoltaics	Multiplier of the Ba- you would have	Multiplier of the cost of maintenance Batteries	Multiplier of the cost of replacement of Batteries	Inflation Yearly
0.3148	0	50%	50%	50%	1 %	10%	10%	10%

One of the conclusions that derive from this analysis is that even with an unrealistic acquisition value for the batteries (1% of the current market cost) and even considering a 90% reduction in the cost of operation and maintenance, even so, the addition of the Energy storage with batteries is not economically more viable than using only the grid with the photovoltaic generation system. It is worth mentioning that in this case the values are combined with a 50% reduction in the costs of purchasing, maintaining and replacing photovoltaic panels.

CONCLUSIONS

What was identified from this study is that the technologies for generating electrical energy using photovoltaic panels, as well as for energy storage, are economically and technically viable to be applied in the company studied, which has a practically level demand profile, and potential for similar companies. It was also observed that some factors, such as inflation and the replacement rate, have little impact on the cost of energy consumed by the load, compared to other variables. In contrast-
Given the consumption rate per kWh, the cost of acquiring and maintaining photovoltaic generation technologies has a great influence on the modeling of a solution of this type.

Finally, despite the potential technical-economic viability of this type of system, a simple payback period of close to 8 years was noted, in relation to the current contract and the consumption profile of the company studied here, and this could make practical installation of this difficult. system. However, from the sensitivity study, it can be seen that in the case of a higher cost of energy from the grid or in the case of a drop in the costs of applied technologies, the result of return on capital can be strongly reduced. Therefore, it is valid to state that with the cheaper cost of existing energy storage technologies and the continuous evolution of energy storage technologies,

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photovoltaic panels, the use of these combined systems can be better made viable, mainly for the implementation of distributed micro-generation in Brazilian industries.

In future work, an analysis is recommended regarding the use of diesel generators as a power generation option and lithium ion batteries for storage and the application of intangible gains for this type of project, such as green seal and sustainability marketing. Another recommendation for future studies, for the Homer software developers themselves, is to consider fines in case the contracted demand power is exceeded, as this limitation exists in the current version, and in the formulation for demand monetization. It is also recommended, using a methodology other than simulations in the Homer software due to its limitations, to evaluate the implementation of energy storage systems exclusively to meet demand during peak hours.

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TECHNICAL-ECONOMIC FEASIBILITY STUDY FOR THE INSERTION OF PHOTOVOLTAIC SYSTEMS AND ENERGY STORAGE IN A BRAZILIAN INDUSTRY

Abstract.*This paper discusses alternative ways to reduce the cost of electricity in companies in the industrial sector, focusing on the technical-economic feasibility analysis, which depends on factors such as cost of components, legislation, and technological advances. Recent studies show that the technical-economic viability has become increasingly favorable for the use of renewable energies, especially for residential consumers, but that there are still challenges to be overcome in the case of scenarios with storage. The study analyzed the technical-economic feasibility of installing a hybrid system of electrical power generation, composed of photovoltaic panels and battery storage, in an industry. The company's current contract in the free market was compared with other concessionaire tariffs, and it was verified that the current contract is less favorable for the installation of the alternative system due to the low cost of energy available. The most viable option was identified as a hybrid system composed of the electrical grid plus 3,200 kW of installed photovoltaic energy and a current converter, which indicates that the system is feasible both technically and economically. However, the payback was considered long, which may hinder its implementation in practice. The study suggests, based on the sensitivity analysis, that with the cheaper technologies for photovoltaic panels, the increase in their efficiency and the variability in the price of energy tariffs, the implementation of distributed microgeneration in Brazilian industries can be better made possible.*
Keywords*: Photovoltaic generation, Energy storage, Binomial pricing.*

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