

**ANALYSIS OF THE BENEFITS OF PHOTOVOLTAIC PLANTS: APPLICATION  
OF SYSTEM DYNAMICS AND COMPUTATIONAL MODELING**

*ANÁLISE DOS BENEFÍCIOS DAS USINAS FOTOVOLTAICAS: APLICAÇÃO DA DINÂMICA DE  
SISTEMA E MODELAGEM COMPUTACIONAL*

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**Resumo**

A energia solar é considerada uma fonte de energia limpa e renovável, pois utiliza a radiação solar para a geração de energia elétrica, diminuindo assim os impactos causados ao meio ambiente. Apesar de ainda ser considerada uma fonte de energia que necessita de altos investimentos para geração de energia elétrica, os custos para implantação de placas solares fotovoltaicas vêm diminuindo drasticamente ao longo dos

anos, o que tem possibilitado a ampliação do uso desta fonte de energia para os mais variados fins. O objetivo deste artigo é simular cenários para verificar o impacto da utilização de placas solares fotovoltaicas em uma Instituição de Ensino Superior (IES), com o intuito de gerar energia elétrica que supra parcialmente (50%) ou totalmente (100%) o consumo elétrico desta IES. Com isso pretende-se identificar qual a economia financeira gerada pela adoção de placas fotovoltaicas. Foi utilizado o método Dinâmica de Sistemas, o qual permite o estudo do comportamento dos sistemas ao longo do tempo, possibilitando a avaliação das consequências de nossas decisões. Por essa razão e a necessidade de estudar os impactos da geração de energia solar em um horizonte temporal futuro decidiu-se utilizá-la na modelagem e simulação computacional. Foi desenvolvido um modelo de simulação o qual foi validado por três cenários diferentes. Os resultados gerados pelo modelo de simulação indicam que a implantação de placas solares fotovoltaicas para geração de energia elétrica é uma alternativa que proporcionará redução de gastos com energia elétrica a longo prazo. Quanto mais longo for o período considerado maior será a redução dos custos com eletricidade. Com isso conclui-se que, apesar do alto valor financeiro do investimento inicial, a implantação de um sistema de energia solar fotovoltaica é vantajosa financeiramente a longo prazo, seja em um cenário onde 50% ou mesmo 100% da energia elétrica da instituição seja proveniente do sistema de placas solares fotovoltaicas.

**Palavras-chave:** Energia solar fotovoltaica. Dinâmica de Sistemas. Modelagem computacional

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## 1 INTRODUCTION

Energy is one of the main elements of modern society and permeates all sectors of society - economy, work, environment, international relations - as well as our own lives - housing, food, health, transport, leisure. It is necessary for the production of goods based on natural resources and for the provision of services in order to meet the demands of an ever-increasing population. According to Hinrichs, Kleinbach and Reis (2014), the supply of energy, in an adequate and reliable way, is also necessary for economic development, as was observed in the modernization of the West, which went from one rural society to another, urban and rich, through the use of modern technologies based on a wide range of scientific advances, which have been energized by fossil fuels as energy sources.

The global energy matrix is composed of several primary sources, among which oil, natural gas, mineral coal, uranium, hydraulic energy, solar energy, wind energy, in addition to energy from biomass. However, despite this diversity, the consumption of fossil fuels, which are non-renewable resources, prevails over the others (TORRES, 2012). As described by Braun-Grabolle (2010), the energy issue has been considered a global concern, with crises in the electricity sector happening frequently, and energy sectors in different countries undergoing profound transformations.

The growing demand for energy worldwide has meant that great importance is associated with the exploration of new sources of energy (PALZ, 2002; ALDABÓ, 2002). To guarantee energy security, it is necessary for countries to develop new forms of energy generation and technologies that promote access to electricity, as has been happening in countries such as Germany, the United States, Spain, France, Italy and Japan, which are developing mechanisms to reduce dependence on fossil fuels, with the introduction of renewable energies in their energy supply systems (CARVALHO, ABREU; NETO, 2017).; According to Angelis-Dimakis et al (2011), an example of a renewable energy source is the sun, making it possible to directly transform sunlight into electrical energy through the photovoltaic effect. The generation of energy through the conversion of solar energy directly into electrical energy carried out through photovoltaic cells has the advantage of its simplicity, the absence of any moving mechanical part, its modular characteristic, the short installation times expected, the high degree of reliability of the systems and its low maintenance. (NOGUEIRA; SOUZA, 2012).

Jannuzzi and Melo (2013) argue that the use and dissemination of photovoltaic solar energy generation technologies are viable options due to three factors: high cost of residential energy, high availability of solar radiation, and reduced prices for solar modules and panels. Although solar cells remain relatively expensive, their price has dropped more than 1000 times from 1950 to the present day (HINRICHES; KLEINBACH; REIS, 2014).

Santos and Jabbour (2013) cite studies related to the use of photovoltaic solar energy in hospital institutions in countries like Iran, Iraq, Sierra Leone, Italy and Ghana. The results of these studies indicated that, with the introduction of photovoltaic systems in hospitals, there was a reduction in operating costs and a reduction in fossil energy consumption.

In this context, this work aims to simulate scenarios to verify the impact of the use of photovoltaic plates in a Higher Education Institution (HEI), in order to generate electricity, which supplies part or total of the HEI's electrical consumption. From this perspective, the following research problem arises: What is the financial savings generated by the adoption of photovoltaic plates?

The structure of the article is divided into five parts, organized in order to bring together all aspects of the research. Thus, the first part contains the introduction, in addition to delimiting the research problem and the objective. The second part contains the research method, with the identification and description of the procedures that were adopted in the execution of the work. In the sequence comes the theoretical framework, which presents the theories, concepts and studies that guided the research, being addressed the theoretical assumptions of the following themes: "Photovoltaic solar energy" and "Systems dynamics". Then the development and experiment of the Computational Model is presented, and in the last stage are the final considerations, which are aligned with the proposed research objective and problem.

## **2 RESEARCH METHOD**

The research is characterized by being an exploratory investigation, with a quantitative approach. According to Gil (2010), exploratory research aims to expand knowledge about a certain phenomenon by exploring a certain reality. To achieve the objective proposed by the research, the Systems Dynamics method, defined by Ford (2009), is used as a combination of stocks and flows that use a computational structure to be simulated.

The systems dynamics methodology allows the study of the behavior of systems over time, enabling the evaluation of the consequences of our decisions. For this reason and the need to study the impacts of solar energy generation in a future time horizon, it was decided to use it in computational modeling and simulation (VENSIM, 2004).

Among the tools of System Dynamics, computational modeling was used, which is characterized by Andrade et al (2006) as a set between qualitative work (systemic map) that aims to analyze and capture data, and a quantitative model, in this case the computational model, which requires techniques from the field of Systems Dynamics for its execution. Modeling in Systems Dynamics consists of representing the processes of a system. For its development, it is necessary to recognize the flows that convert resources in different states, which implies knowing its developed systemic map (ANDRADE et al, 2006).

## **3 THEORETICAL REFERENCE**

In this part, an overview of works already carried out under the topic in question will be exposed, in which the main theoretical aspects regarding photovoltaic solar energy and systems dynamics will be addressed, which will support, provide consistency and support the analyzes developed in the study.

### 3.1 PHOTOVOLTAIC SOLAR ENERGY

Solar energy uses sunlight for its conversion. This energy is captured by solar panels, formed by photovoltaic cells and transformed into electrical or mechanical energy. This solar energy is still little used in the world, since the cost of manufacturing and installing solar panels is still very high. Another problem is the difficulty in storing solar energy (DEPARTAMENT OF ENERGY US, 2011). Brazil is one of the countries with the greatest potential in the world regarding the generation of energy from the sun's rays. This is explained by the fact that we have a vast territory with a high incidence of the sun's rays (STEPHEN, 2011).

The use of solar energy is now readily associated with “clean energy” proposals, together with other solutions that aim to reduce the impact of electricity generation on the environment. In this context, photovoltaic solar energy appears as an alternative and renewable energy source, as it uses solar radiation to generate electricity. According to Hinrichs, Kleinbach and Reis (2014), renewable energy sources represent 8% of the energy produced in the world, and this percentage has been increasing rapidly, with photovoltaic energy being the second renewable source with the highest growth in the world, with 35% of growth per year. Still, according to Hinrichs, Kleinbach and Reis (2014), renewable energy resources have advantages in a world where energy sources are increasingly limited and can be used in various activities, through appropriate technologies and with a reduction in environmental damage.

According to Machado and Miranda (2015), producing electricity using solar energy is not new, since in 1839 the French physicist Edmond Becquerelo observed the photovoltaic effect, in which two brass plates immersed in a liquid electrolyte produced electricity when exposed to sunlight. In 1883, the first solar battery made with selenium sheets was built. Despite having an electrical conversion efficiency of only 1%, his device had a lot of repercussions, because people did not believe that energy could be generated without burning fuels. The first photovoltaic solar cell was developed in 1954 by an American company (MACHADO; MIRANDA, 2015; BRAUN-GRABOLLE, 2010).

According to Rüter (2004), through the photovoltaic effect, solar cells directly convert the energy of the sun into electrical energy in a static, silent, non-polluting and renewable way. This process consists of a photoelectric effect characterized by the production of an electric current between two parts of different material, which are in contact and exposed to light, which provides the conversion of solar energy into electrical energy (PALZ, 2002).

The functioning of solar cells for the direct conversion of sunlight into electrical energy is obtained through the use of solar plates, made up of solar cells, as explained by Palz (2002). The photovoltaic cells are grouped in a solar panel in order to obtain protection and durability, which will be connected to other panels in a photovoltaic solar system. This system is composed of elements such as solar panels, solar inverter, the system for fixing solar panels, cabling, connectors and other standard electrical materials (PORTAL SOLAR, 2018).

Silva (2008) argues that a disadvantage of this mode of energy generation is high investment. With this, the return on investment is long term, which causes a certain lack of interest in its use. Initially, photovoltaic solar cells had a high cost and were used to

generate energy for satellites. Over time, technology evolved and became economically viable for terrestrial applications (RÜDTHER, 2004).

According to Silva (2008), to make the use of photovoltaic energy economically viable, several scientific advances were necessary, such as, for example, the use of new materials that increased the efficiency of cells. In fact, there have been so many advances in the development of photovoltaic energy generation that there are already cells with efficiencies above 40%, even though they are not yet available on the market.

The sun is one of the most abundant elements in nature and essential for human survival. In this regard, according to Santos and Jabbour (2013), Brazil is in a privileged position to explore this natural wealth. Because it has much of its territory among the tropics, the use of photovoltaic cells is favored due to the higher incidence of daily solar radiation per square meter.

The use of cells that convert solar energy into electrical energy is a great alternative for generating energy, mainly because it is a clean source causing less environmental damage. According to Rüter (2004), the economic feasibility of using photovoltaic panels has only become possible due to the evolution of technologies for producing solar cells. The application of photovoltaic solar energy can provide benefits to users in general, to the national electrical system and to society (RÜTHER, 2004).

Photovoltaic generation makes use of semiconductor elements, capable of generating electricity from the direct conversion of solar energy into electrical energy through solar cells (photovoltaics). Although it may be simple, this conversion process depends on the characteristics of each semiconductor and the quality of the materials used in the manufacturing technology.

A photovoltaic system is basically composed of arrays of photovoltaic cells in the series and / or parallel configuration. Since each cell is capable of typically generating between 1W to 3W of power, it is necessary to combine cells when you want to increase the level of power generated. The structure resulting from this combination is called a photovoltaic module, commercially found with power values that typically range from 5W to 245W (KYOERA SOLAR, 2017). Depending on the power, voltage and current level desired in the project, the photovoltaic modules can also be associated in series or parallel, finally constituting a photovoltaic panel.

One of the fundamental aspects for the installation of photovoltaic systems is the knowledge of the solar radiation characteristics of the place where the installation is to be carried out. These data can be obtained through information from the weather station database. The ABNT NBR 10899: 2013 standard defines the main technical terms related to the photovoltaic conversion of solar energy, and establishes the following definition for solar radiation "Solar radiation energy flow density, usually measured in  $KW / m^2$  or in  $mW / cm^2$ " (ABNT, 2013).

Solar radiation is the main variable that affects the power generated through photovoltaic cells. In addition to solar radiation, the operating temperature of the cells also influences the amount of power generated, since the output voltage of the photovoltaic cell is altered as a function of the ambient temperature. The effect of the variation of the operating temperature on the power can be observed in the

characteristic curves of voltage and current (curves I-v) of the output of a photovoltaic module (BERNARDON et al, 2014).

### **3.2 SYSTEM DYNAMICS**

For Geum, Lee e Park (2014) systems dynamics is the combination of theories, methods and philosophies, aiming at analyzing the behavior of systems. For Bueno (2013), the system dynamics consists of a method developed for the analysis of the cause and effect relationships of certain variables of a system, be it organizational or social.

According to Bueno (2013) the addition of information causes actions (flows), changing the state (level) of a system, when a period of time has elapsed, generating two types of feedback cycles: the negative (or equilibrium) - in which the system reacts to changes, compensating for them; and the positive (or self-reinforcing) - in which the system amplifies possible disturbances.

For Vaz e Maldonado (2016), the main premise of systems dynamics refers to the importance of the structure of the system, that is, the physical elements, the decision rules and their interrelations, to explain the behavior of the system under study.

The second premise of the dynamics of systems, according to the aforementioned authors, is related to the responses of the system to the actions of decision makers in the form of accumulation or reduction (of matter, energy or information).

On the other hand, as advocated by Vaz & Maldonado (2016), the dynamics of systems assume that there are several stocks within socio-techno-economic systems, influencing each other through their flows and dynamically, this statement refers to the third premise of the dynamics of systems: the processes of feedback or feedback, that is, every action or decision eventually produces a reaction of the system, changing, therefore, the state of the system under study, being that the socio-techno- Economic factors are formed by more than one feedback loop, both positive and negative.

Finally, the fourth and last premise of systems dynamics, for Vaz & Maldonado (2016), concerns the effect of the time lag, or delay, that is, the existence of a gap between decisions and the respective results generated by them, dynamically influencing the system's behavior.

## **4 DEVELOPMENT AND EXPERIMENT OF THE COMPUTATIONAL MODEL**

The study was conducted at an HEI located in the central region of the State of Rio Grande do Sul. The information used in the experiment was provided by the institution's Pro-Rector of Infrastructure (PROINFRA) and was extracted from the energy bills of its main campus covering the total period of 36 months.

In order to arrive at the values used in the model, it was necessary to tabulate the data provided by the IES partner of the study in an MS Excel spreadsheet. Subsequently they were organized in order to understand the mathematical relationships that occurred between them.

Due to the complexity of the calculations, which is due to the large number of elements that make up an energy bill (ranging from the collection of taxes, to some specific legal discounts granted in payments made by institutions of the federal public administration), we opted for the simplification of the model. Thus, its elements and the relationships between them are represented graphically in the figure below:

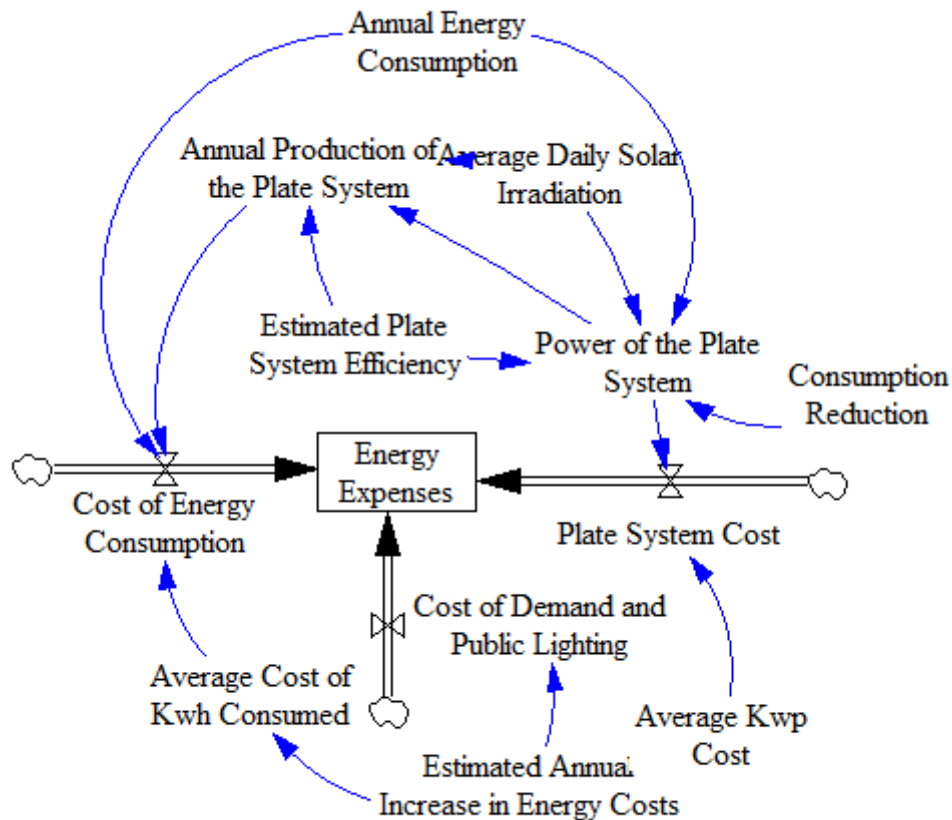


Figure 1. Simulation model developed  
Source: Authors (2023).

The Cost of Demand and Public Lighting represents the aggregate of values that in the energy bill are not affected by the Plates System. It is characterized by being constant, in theory they would not change, unless there is a change in one of its calculation components. The amount defined in this constant was R \$ 3,438,291.26. When calculating the peak demand and off-peak demand contractor, the rates charged by the concessionaire in June 2018 (applying the average taxation of PIS, COFINS and ICMS for the last 12 months), the mandatory retentions corresponding to Law 10.833 / 2003 and the monthly public lighting contribution, their values are detailed in the table 01.



### Cost of Demand and Public Lighting

Constants	Value
Peak demand contractor	3 mW
Out-of-peak demand contractor	5 mW
Contracted kW tariff - peak demand	R\$ 32,28
Contracted kW tariff - off-peak demand	R\$ 21,67
Total mandatory retentions (10,833 / 2003)	9,45%
Public lighting contribution fee	R\$ 163,00

Table 1. Data used to form the Demand Cost and Public Lighting value

Fonte: Autores (2023)

The Average Cost of kWh Consumed is one of the constants that help to form the Annual Energy Consumption Cost. The value defined for this component in the simulation was R \$ 0.55717431. In order to determine the amount of kWh consumed paid by the HEI in the simulation, it was considered: the annual peak and off-peak energy consumption, the tariffs charged by the concessionaire in the month of June 2018 (applying the average taxation of PIS, COFINS and ICMS for the last 12 months), total days of green, yellow, red I and red II flag from tip to tip and from tip to tip, mean peak power factor and out of tip, (last 12 months), minimum power established by ANEEL and the mandatory retentions corresponding to Law No. 10,833 / 2003.

Annual Energy Consumption is the second of the three components that make up the calculation of the Annual Energy Consumption Cost. Unlike the other two elements previously mentioned, a longer time perspective was sought here: 36 months. When attesting to an annual seasonality in energy consumption, a comparison of the last three cycles (years) was made to verify if there was a trend of growth in consumption. Discarding the hypothesis, it was decided to make an annual average to obtain this value, thus adopting it as standard consumption, that is, 15,820,546.44 kWh / year.

The unit of measurement used to measure the Potential of the Photovoltaic Plate System is the Watt-peak (Wp), it is also allowed to use its multiples as kilowatt-peak (kWp) and megawatt-peak (MWp). In order to establish Wp Average Cost, market research was carried out, seeking the best cost-benefit ratio for photovoltaic energy production kits. We opted for the kit that offered the power of 15.6 kWp, costing R \$ 64,390.00. The estimated freight (3.5%), the estimated project value (7%) and the installation value (30%) were added to this value, totaling R \$ 90,467.95. This resulted in a value of R \$ 5.79922756 per Wp. The estimated efficiency of the slab system was arbitrated at 83%, the value being the standard efficiency rate for a project.

Average Cost of kWh Consumed

Constants	Value
Peak annual consumption	1.406.669,11 kWh
Annual off-peak consumption	14.413.877,33 kWh
Peak kWh tariff consumed	R\$ 0,45257
Off-peak kWh rate consumed	R\$ 0,28266
Peak kWh transmission tariff	R\$ 0,06167
Transmission rate of off-peak kWh	R\$ 0,06167
Additional yellow flag per kWh consumed	R\$ 0,01000
Additional red flag I per kWh consumed	R\$ 0,03000
Additional red flag II per kWh consumed	R\$ 0,05000
Consumption tariff for reactive kWh	R\$ 0,29682
Total days of tip green flag	118,17689
Total off-peak green flag days	118,67741
Total days of yellow flag tip	90,78239
Total off-peak yellow flag days	89,73265
Total days of pink tip flag	93,04072
Total off-peak pink flag days	93,58993
Total days of red tip flag	63,00000
Total red flag days off-peak	63,00000
Minimum power factor established by ANEEL	92,00%
Average peak power factor	90,36%
Average off-peak power factor	90,24%
Total mandatory retentions (10,833 / 2003)	5,85%

Table 2. Data used to form the Average Cost of kWh Consumed

Fonte: Autores (2023)

To define the Average Daily Solar Irradiation, data from the Reference Center for Solar and Wind Energy (CRESCESB, 2018) were used using the coordinates of the HEI. To make the weighted average between the monthly irradiations and their corresponding number of days in each month, the horizontal plane (0 ° N) was used, without inclination, which totaled 4.47287671 kWh / m<sup>2</sup>.day. The data mentioned above are summarized in the table 03.

Table of Model Values

Constants	Value
Cost of Demand and Public Lighting	R\$ 3.438.291,26
Rate of consumed Kwh	R\$ 0,55717153
Annual Energy Consumption (kWh)	15.820.546,44
KWp cost	R\$ 5,79922756
Estimated Plate System Efficiency	83%
Estimated Daily Solar Irradiation (kWh / m <sup>2</sup> .day)	4,47287671

Table 3. Data used to feed the scenarios

Fonte: Autores (2023)

Once the model's constants have been established, we will seek to clarify the mathematical relationships between the other elements not previously exposed. The Cost of the Plates System (A) is the total investments required to implement the proposed photovoltaic project. To define this value, the Power of the Plate System (B) and the Average Cost of the Wp (C) are taken into account. In turn, the Power of the Plates System (B) depends on Estimated Efficiency of the Plates System (D), Average Daily Solar Irradiation (E) and the expected Reduction of Consumption (F).

So far, two elements of cause for the Cost of Energy Consumption (G) have been presented: Annual Energy Consumption (H) and Average Cost of kWh Consumed (I). The Annual Production of the Plates System (J) is the missing component, which depends on the Average Daily Solar Irradiation (E), Estimated Efficiency of the Plates System (D) and the Potency of the Plates System (B). And finally, we have accumulated Energy Expenses (K), which is the sum of the Cost of the Plates System (A), Cost of Demand and Public Lighting (L) and Annual Energy Consumption Cost (G). Below are the mathematical equations supplied by the constants already presented:

$\text{Plate System Cost (A)} = B * C$ $\text{Plate System Power (B)} = (F * H) / (E * D * 365)$ $\text{Annual Production of the Plate System (J)} = E * B * D * 365$ $\text{Energy Consumption Cost (G)} = (H - J) * I$ $\text{Energy Expenditure (K)} = A + L + G$
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Frame 1. Equations model

Fonte: Autores (2023)

Finally, by varying the values of Consumption Reduction, it was possible to generate alternatives for photovoltaic energy production scenarios, in a panorama of fifteen years. It was decided to choose three scenarios. The first represents the current system, it is called the Current Scenario (0%) in which there is no investment in photovoltaic

energy production. The second, called the Plaque 50% Scenario, will simulate the first proposal for the implementation of the plaque system, with an investment equivalent to half of the annual energy production consumed by the HEI. The last one, Plate Scenario (100%), will simulate the accumulation of Energy Expenses when the annual energy consumption is supplied by the production of photovoltaic panels. In the next session, the result of the computational experiment will be presented.

#### 4.1. EXPERIMENT AND RESULT

After defining the equations, the time horizon of the projections and the proposed scenarios. The proposed model was executed in a simulation using the Vensim software (VENTANA 2016). For experimentation in the software, a computer with a Pentium Core i5 processor and 8 Gb of RAM was used. The simulation execution time was in the order of hundredths of seconds.

For this article, only the effect on Energy Expenses resulting from IES's investment decisions in photovoltaic energy was of interest. Figure 2 compares the evolution of the accumulation of expenditures in the proposed scenarios and time horizon.

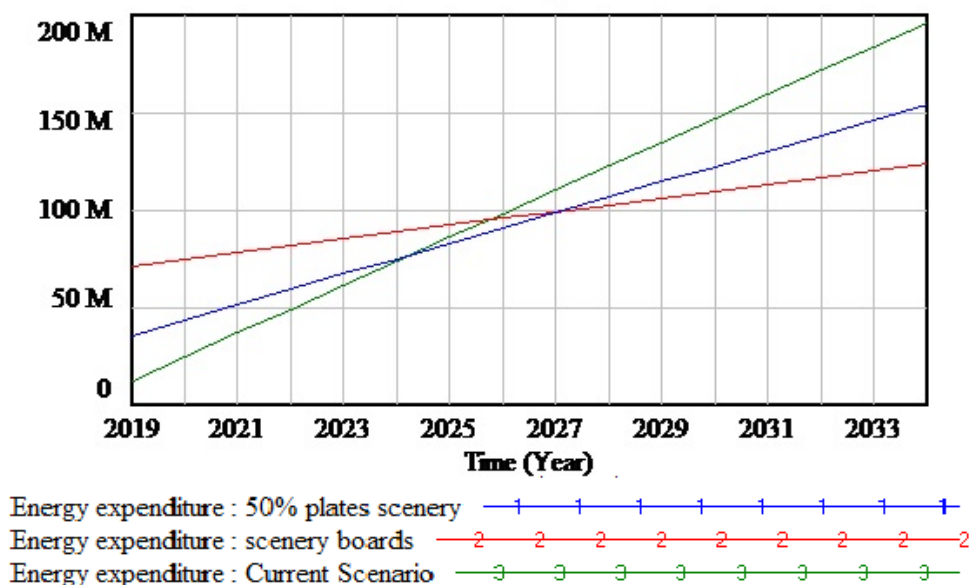


Figure 2. Energy expenditure  
Source: Authors (2023)

Comparing the three simulation scenarios, it appears that the Plate Scenario, although it has the highest initial cost (R \$ 67,607,000.00), is the one that accumulates the lowest expenses with electricity (R \$ 123,590,000.00) end of the period. The Plaque Scenario 50%, although it presents a lower accumulation of expenses (R \$ 153,693,000.00), when compared to the Current Scenario (R \$ 196,048,000.00), does not exceed the reduction

of expenses provided by the most favorable scenario. It should be noted that the implementation of the project that provides 50% of the energy consumption has an initial cost of R \$ 33,853,000.00.

It is expected that when applying to the plate system, there will be a reversal in the accumulation of electricity costs. The greater the reduction in spending, the greater the need for initial investments. At the same time, it is clear that the greater the initial investment, the greater the time needed to overcome the Current Scenario. For example, it is only around the year 2027 that the Plate Scenario can be expected to match the accumulation of expenditures that the Current Scenario. Whereas, much earlier, between 2024 and 2025, the Plate 50% scenario already reverses the accumulation of expenses.

## 5 FINAL CONSIDERATIONS

The Brazilian public administration is experiencing a contingent of successive budget cuts. Institutions are obliged to reduce their operating costs. Actions that cut or decrease expenses tend to be valued more as they are becoming a necessity.

If we consider that the total energy consumption of the HEI can be met in full by implementing a photovoltaic project, the option of investing in solar energy may be the way out to reduce expenses with electricity consumption.

Along with wind, geothermal and tidal power generation technologies, the solar has been viewed with good eyes by the lesser environmental impact caused. Although there are, for example, impacts on the extraction and processing of silicon (component of the panels), once installed, the plates do not generate pollution.

Over time, the cost of photovoltaic energy has been falling, its popularization has allowed the market to practice more affordable prices successively. But even so, the costs of implementing projects that use this technology continue to require high investments to materialize.

The present study proposed, using simulation, to design three scenarios to assess the financial impact that a possible photovoltaic plate project could cause in the HEI. The model was validated using the data provided by the HEI itself. Due to the complexity of the calculations to define the values of the energy bill. We found it convenient to simplify the model, setting aside taxes, withholdings or any additions of yellow, red I and red II flags in calculations and graphical representations.

From the year 2019 to the year 2024, the Current Scenario, that is, without the installation of photovoltaic plates, is the one that offers the lowest expenditure on electricity. As of the year 2027, the Plate Scenario, that is, with 100% electrical energy consumed produced by the solar project, is what provides the lowest expenditure on electricity. In the meantime, the most favorable of the scenarios is that which represents the partial implementation (50%) of the production of the kWhs consumed in the institution, the Plate 50% Scenario.

Therefore, evaluating the scenarios, despite the high initial value of the investment, the implementation of a photovoltaic solar energy system seems to be economically sustainable, whether it is producing 50% or 100% of the energy consumed in the institution. But to reach more precise conclusions, it would be necessary to consider other factors, which may be the target of further studies, such as the cost of maintaining the slab system, the projection of possible increases in energy tariffs and, if applicable, the cost of financing. from the project.

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