# Technical Feasibility Study for Improving the Implementation Process of a 2MW Hybrid Power Plant using Operational Research

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## Abstract

The concept of hybrid power plants has driven several studies to optimize the energy generation process. In Brazil, the focus country of this work, despite having great potential for alternative energy sources, still concentrates its electric production in hydrographic sources. The main issue with hydrographic sources relies in their nature, which are inconstant and due to the evident climate changes, their scenario can be even more aggravated. This article proposes a study of the application of operational research as a way of improving the implementation process and choosing a location for a hybrid plant in Brazilian territory. This work presents quantitative-qualitative analyzes on the subject and a proposal for the implementation of a plant through the center of gravity technique. The data was provided by a large company in the energy sector. As a result, the calculation of the optimal point of implementation was obtained, resulting in a necessary investment of about 38,896,000.00 Brazilian Reais (BRL), with a payback period of 12 years.

**Keywords:** Hybrid Power Plants; Technical viability; Energy; Gravity center; Operational Research.

## 1. Introduction

The negative effects caused by conventional energy production have been widely discussed since the United Nations Conference on the Human Environment (Stockholm) convened by the UN in 1972 (ONU, 2021). As the main subsequent event, it can be mention the Kyoto Protocol signed in 1997, which established goals for the reduction of greenhouse gas emissions and additional mechanisms for achieving these goals. One of these mechanisms is the Clean Development Mechanism (CDM), which seeks, through the implementation of project activities, to reduce GHG (Greenhouse Gas) emissions, or to increase CO2 removal, through investments in more efficient technologies, replacement of fossil energy sources with renewables, among other means (Lazaro & Gremaud, 2017).

Non-renewable energy sources, in addition to causing high emission of greenhouse gases, are also subject to a shortage of raw materials, as occurred in the oil crisis in 1973. Even with these unfavorable variables, these energy sources still represent the largest part of the world energy consumption. According to data released in 2020 by the IEA (International Energy Agency, 2020), non-renewable energy sources such as coal and oil represent about 73.8% of the total consumption, while renewable energy sources represent about 26.2%. In Brazil, hydroelectric plants are the most significant source of electricity, representing 61.27% of its total (Pereira, et al., 2017).

According to the National Electric System Operator, the reservoirs of the systems that generate 70% of the energy of the country operates with 19.59% of total capacity, which means that the country is experiencing the worst water crisis in 91 years (ONS, 2021). These facts cause greater urgency in the search for more viable alternatives in the energy matrix.

In order to implement it, it is necessary to structure the Project Management, which according to PMI, is defined as the temporary effort undertaken to create a unique product, service or result (PMI, 2017). These processes, in addition to generating quantitative-qualitative analysis, can provide an optimization process, using operational research (OR) as a tool. OR is a mathematical method composed of statistical and algorithmic models that are used to help in decision-making tasks (Giordano, Fox, & Horton, 2013).

Thus, the general objective of this article is to propose the analysis of the process of implantation of an energy plant based on the production of wind-photovoltaic hybrid energy, in order to present a quantitative-qualitative evaluation with a proposal of mathematical modeling for optimization of its processes. In this way, the specific objectives are to evaluate the implementation process, to weave quantitative-qualitative comparative analysis between conventional plants and hybrid plants, and verify through mathematical modeling and simulations the possibilities of optimization of the process.

In view of the facts previously mentioned, the work is justified by the risk of an energy crisis in the country, which requires an alternative energy source, as well as by the growing trend of clean and renewable energy generation motivated by international agreements.

# 2. Materials and Methods

## 2.1 Theoretical Foundations

Three concepts were the references of the work: Energy Production, Strategic Financial Planning and Operational Research.

This work aims to analyze two of the forms of sustainable and renewable energy production, which are photovoltaic energy and wind energy, and the operation of both together in a hybrid power plant (Tessaro, 2006; ANEEL, 2021).

- **Photovoltaic Energy:** photovoltaic energy, also known as solar energy, bases its operation on silicon photovoltaic cells (Sc) combined with boron, to create positive charges, and with phosphorus, to create negative charges. When the plates capture solar radiation, the silicon electrons are excited along with their combinations, resulting in a release of electrons from the atoms, which generates the direct electric current.
- **Wind Energy**: wind energy is known for capturing energy by the wind through wind turbines. Its generation is produced by wind turbines that, from the force of the wind, there is a movement of the blades, which rotate the rotor inside the nacelle, generating mechanical energy.
- **Hybrid Power Plant:** a hybrid power plant is the combination of two or more sources of energy or power, including forms of storage.

The wind and solar energy can be combined, so that during the day the photovoltaic plant would produce energy at its peak, while at night the energy produced by the wind would be responsible for its maximum capacity, using the efficient production of both sources. Another interesting point of this plant is the reduction of operation and maintenance costs, as there is the use of the transmission line, as well as the costs of logistics during the project.

To verify the economic viability of a project, it is necessary to prepare a Strategic Financial Planning aiming at observing what the costs and expenses will be. According to (Freitas & Rossi, 2021): "*Planning is the key to business management. The corporate budget is a financial plan capable of leading the company to its goals, serving as a control of operations in the short and long term.*".

The process of implementing strategies requires changes in the organization. Therefore, the availability of material and financial resources is essential for the strategies to be implemented, as the lack of resources or delays can become a reason for well-formulated strategies to fail.

Finally, for the optimization of this implementation process, Operational Research (OR) is implemented, which consists of a mathematical modeling tool that is applied in the resolution of real problems, helping on the optimal decision-making tasks during the planning and execution of projects. In summary, it consists of the following steps: formulate the problem, build the model from the established metrics, obtain the solution, test the result and, finally, implement, correlating the variables of the problem (Souza, Teixeira, & Simão, 2017).

In the present research, more specifically, Linear Programming Problems (LP) were used in OR analysis, which consists of a method for solving optimization problems, with restrictions in the objective function that are linear in relation to the control variables. Based on this LP modeling, the present work uses the Center of Gravity technique, which allows, through the application of equations 1, 2, 3 and 4, to define a optimal location (Kreyszig, Kreyszig, & Normington, 2021).

$$Di = xi \,.\, Ki \tag{1}$$

$$Di = yi \,.\, Ki \tag{2}$$

$$Xx = \frac{\sum_{i=1}^{I} \quad xi \,.\, \rho i}{\sum_{i=1}^{I} \quad \rho i} \tag{3}$$

$$Xy = \frac{\sum_{i=1}^{I} \quad yi \,.\, \rho i}{\sum_{i=1}^{I} \quad \rho i} \tag{4}$$

Where $X_x$ corresponds to the *x* coordinate (latitude) of the new facility allocation point, $X_y$ corresponds to the *y* coordinate (longitude) of the new facility allocation point, $x_i$ is the latitude of the studied point, with *i* varying from 1 to *I*, $y_i$ is the longitude of the study point, with *i* varying from 1 to *I*, $\rho_i$ is the density of the point, with *i* varying from 1 to *I*, $D_i$ corresponds to the density of each demand point, with *i* varying from 1 to *I*, *and* $K_i$ corresponds to solar irradiance or wind speed data from point *i*, with *i* varying from 1 to *I*.

The equations (1) and (2) result in the densities of reference points, by multiplying them with the database for each application. Equation (3) calculates the optimal latitude of *x* using the densities of *x* and *y*, and, finally, equation (4) calculates the optimal longitude of *y* using the densities of *x* and *y*.

A few papers in the literature have also addressed this subject of implementing hybrid energy plants, and they were considered as a reference for the present work.

In the work of (Campos, 2020) it was carried out an analysis of the complementarity of generation of solar and wind plants and the role of energy storage for hybrid plants. In this work, the author aimed to optimize the dimensioning and operation of wind and photovoltaic plants, together with battery-based storage systems, which could increase the dispatchability of these energy sources.

In (Marozinski, 2018) it was evaluated the generation of a hybrid photovoltaic wind power plant in the state of Rio Grande do Norte, based on the methodological proposal developed by Empresa de Pesquisa Energética - EPE.

## 2.2 Methodology

To achieve the proposed objectives, the following steps were analysed: evaluating the strategic issues of a plant; delimit the OR steps that will be carried out in the research; assess the possible returns and impacts of the project.

Initially, the location of installation of the hybrid plant will be defined, considering five critical evaluation points:

1 - incidence of solar radiation between 5.8 and 6.2 kWh/m².

2 - annual average wind speed at 100m height above 8m/s.

3 - flat terrain (Garni & Awasthi, 2017).

4 - tax benefits in the region (Bittencourt, Busch, & Cruz, 2021).

5 - nearby utility substation.

As a reference for this process, the database of the second edition of the Brazilian Atlas of Solar Energy (2017) was used to define the study sites for the first criterion. For the second criterion, the CRESESB database - Reference Center for Solar and Wind Energy (Brito, 2008) was used, which also makes reference to the Brazilian Atlas of Solar and Wind Energy. In the third criterion, it was necessary to examine the geomorphology map made by the Secretary of State for Science and Technology and the Environment of Paraíba – SECTMA. For the fourth criterion, the data from CINEP - Companhia de Desenvolvimento da Paraíba was used as source. And finally, for the fifth criterion, the data from the Dynamic Map of the SIN, available on the website of the ONS - National Electric System Operator (ONS, 2021), was analyzed. For feasibility and financial analyses, data from a large company operating in the market was used.

After defining the criteria for installing the plant, an OR project is prepared with the objective of defining the best geographic point in Brazil for the execution of the work, according to the following steps:

1 - Formulate the problem: hybrid plants must be built at strategic points, aiming at using their maximum capacity. In this way, the maximum capacity criterion will be used to find the optimal Brazilian geographic point for the execution of the project.

2 - Build the model from the established metrics: to develop the mathematical model, it will be necessary to collect geographic coordinates of the best points of incidence of solar radiation, wind performance, flat terrain, tax benefits and the substations of the concessionaire.

3 - Get the solution mathematical location modeling through Excel support.

4 – Test the result, assessing whether the chosen geographic point has an average incidence of solar radiation between 5.8 and 6.2 kWh/m² day, annual average wind

speed at 100m height above 8m/s, flat terrain, benefits inspectors in the region and the nearby substation of the concessionaire.

5 - Evaluate the implementation process.

Such procedures will then undergo an impact assessment. The next step is to prepare a strategic financial plan, aiming to obtain the best Internal Rate of Return (IRR) for the investor, based on two topics: WORK and OPERATION AND MAINTENANCE (O&M). At this stage, a spreadsheet will be presented with the costs and expenses of the project, involving the following parts:

1 - 1MW wind turbine park.

2 - 1MW photovoltaic generator park, with 3 technologies of photovoltaic panels:

a - Crystalline silicon (c-Si).

b - Microcrystalline amorphous silicon (a-Si/uc-Si).

c - Copper-Indium-Gallium-Selenium (CIGS).

3 - Battery Storage System, with 2 technologies (Ni-Cad and Lithium-ion).

4 - Monitoring and Control Center.

5 - Meteorological station (solarimetric and anemometric).

At the end of the study, to optimize the Implementation Process of a Hybrid Power Plant, an implementation schedule will be prepared, aiming to execute the project management with excellence. From these topics, it will be possible to prove the feasibility of the project.

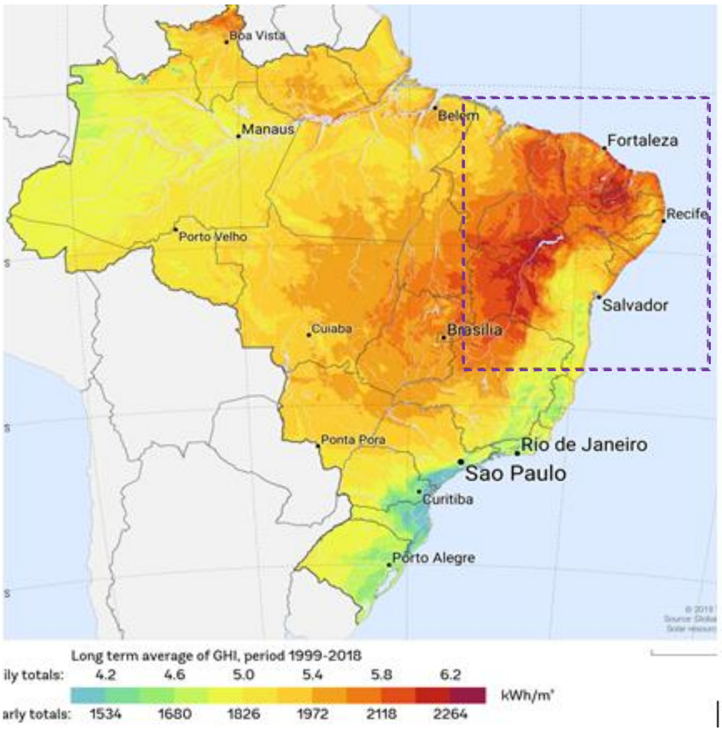
## 3. Results

From the five evaluation definitions delimited for plant implementation strategies, the following results were obtained.

### 3.1 Implementation Definition

According to the first evaluation point, it was outlined through the database provided by Atlas Solar (2019), that the region under analysis would be the Brazilian Northeast, as it has a higher incidence of solar rays, with an average daily incidence ranging between 5.6 and 6.2 kWh/m² in most of its states. Some points such as the coast of Maranhão, regions of the state of Bahia and João Pessoa are the regions with the highest average in Brazil (6.2MJ/m² day, equivalent to 2,264 kWh/m² year), as shown in Figure 1.

*Figure 1: Horizontal irradiation - Brazil*

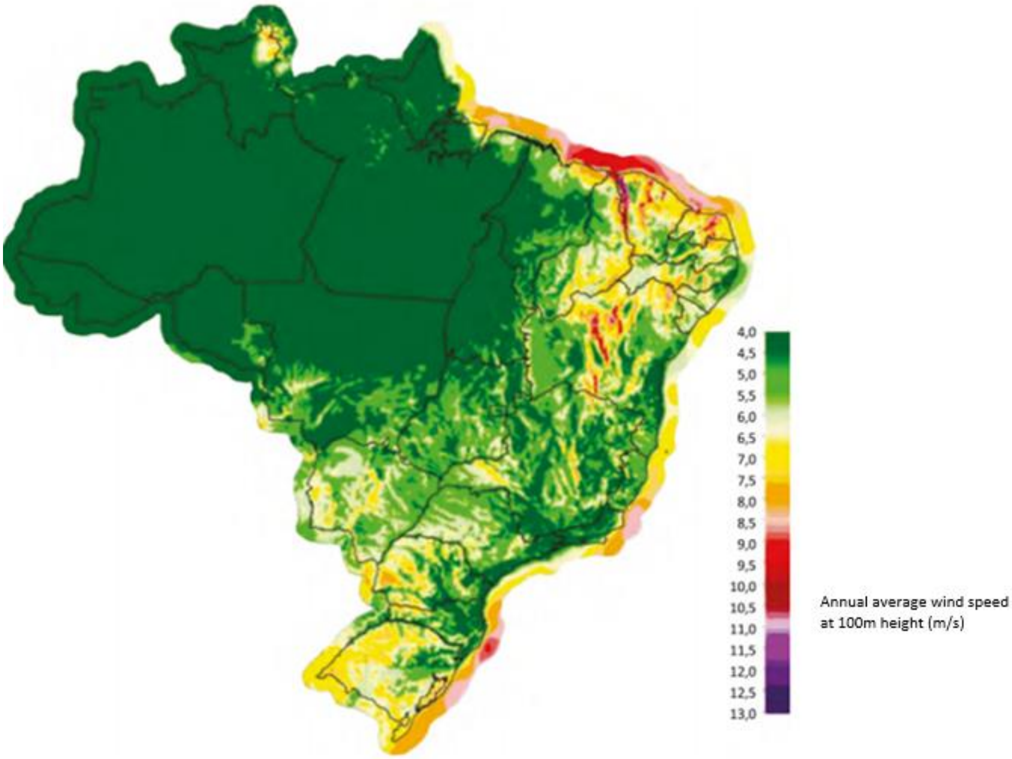



*Source: Global Solar Atlas - Solargis, 2019*

Regarding the second evaluation point, and considering the data from ETENE - *Empresa Transmissora de Energia do Nordeste* - *Northeast Energy Transmission Company* (Bezerra, 2019), which contains the records of annual average speeds and wind power flows in Brazil, it is possible to notice that the Northeast region is the most favorable area among the other regions of the country. This region has the higher rates on the coastal coast and in the offshore perimeter - where it goes beyond the borders of Brazil, also entering the sea - as shown in Figure 2. High slope areas are not economically viable for solar energy projects, as they require earthmoving and landfill works the project. Among the requirements for the implementation of photovoltaic farms, it is indicated that flat areas are chosen, without the presence of rocks and with a maximum slope of 10%, as described by the third evaluation point.

According to data on the topography of Brazil released by the second edition of the Brazilian Atlas of Solar Energy, the central region of the North region, the northern region of the Northeast region and the coastal coast are the areas with less relief in the country, as illustrated in the figure 3 (Atlas, 2021). The tax incentives for reducing income tax and non-refundable surcharges and reinvestment administered by SUDENE (*Superintendência do Desenvolvimento do Nordeste* - Superintendence for the Development of the Northeast), are part of the public policy promoted by the Federal Government with the objective of reducing economic and social inequalities, throughout the regions by creating development opportunities (as elected by the fourth evaluation point). In 2019, investments made in Infrastructure stood out with around BRL (Brazilian Reais) 8.4 billion with 87 requests approved, with emphasis on projects in the energy sector, with BRL 7.4 billion and 55 requests approved.

*Figure 2: Annual average wind speed at 100m height (m/s)*




*Source: (Bezerra, 2019)*

*Figure 3: Topography of the Brazilian territory. SRTM v4 data*


*Source:( Pereira et al.. 2017)*

Among the tax incentives granted by SUDENE there is the Exemption from IRPJ (*Programa de Inclusão Digital* - Digital Inclusion Program), which consists of a 75% reduction in taxes for new projects.

Electric power plants, whether hydraulic, thermal, wind and photovoltaic, generate energy at low voltage levels. The energy generated at these voltage levels initially feeds a transformer, which has the function of raising the generation voltage to levels compatible with the value of the block of energy generated and the distance to be traveled through a transmission system. For this reason, it is necessary that the defined area of implantation also have nearby power substations, which is a set of industrial equipment interconnected with the objectives of controlling the flow of power, modifying voltages and altering the nature of the electric current, as well as to ensure the protection of the electrical system.

### 3.2. Financial Strategic Planning

To assess the economic viability of the project, a financial planning of the project was prepared based on consultation and studies carried out in a company operating in the market. Such organization, as mentioned, is a service provider of projects in photovoltaic and wind power plants. Firstly, a basic budget of the expenses and costs of the hybrid plant installation project was developed, which is detailed in table 1.

*Table 1: Project budget for the hybrid plant*

| DESCRIPTION | MONTHLY (BRL) | COST CENTER |
|---|---|---|
| Company for the elaboration of the electrical/civil project | 760.000,00 | HUMAN RESOURCES |
| Project management company | 936.000,00 | HUMAN RESOURCES |
| Company to build the wind farm | 6.050.000,00 | HUMAN RESOURCES |
| Solar plant installation company | 1.750.000,00 | HUMAN RESOURCES |
| Network adequacy company | 1.000.000,00 | HUMAN RESOURCES |
| Office supplies | 72.000,00 | ADMINISTRATIVE COSTS |
| Vehicle Rental | 156.000,00 | ADMINISTRATIVE COSTS |
| 4ha plot of land | 180.000,00 | ADMINISTRATIVE COSTS |
| Solar panels | 2.700.000,00 | EQUIPMENT |
| Metal structures for solar panels | 530.000,00 | EQUIPMENT |
| Photovoltaic Inverters | 220.000,00 | EQUIPMENT |
| Transformers | 130.000,00 | EQUIPMENT |
| 10 100kWp wind turbines | 16.000.000,00 | EQUIPMENT |
| Electrical infrastructure for wind turbines | 2.000.000,00 | EQUIPMENT |
| Central Storage with batteries | 6.400.000,00 | EQUIPMENT |
| Weather station | 12.000,00 | EQUIPMENT |
| FINAL VALUE | **38.896.000,00** | |

*Source: (Authors, 2022)*

Based on this study, it can be concluded that a total investment of 38,896,000.00 BRL will be necessary, with 10,496,000.00 BRL reserved for human resources such as service providers, expenses for project preparation and training of members; 408,000.00 BRL allocated to administrative expenses such as office supplies, vehicle rental and land where the plant will be installed; 27,992,000.00 BRL reserved for the acquisition of equipment such as photovoltaic panels, wind turbines, inverters and metallic structures. Based on that, to calculate the rate of return of the investment, it was considered that the hybrid plant will generate a power of 2.0MWh, under a tariff for the generation of wind and solar park of BRL196.00/MWh. Considering a period of one year (8,760 hours), the revenue of the plant can be calculated as follows:

Annual Revenue: 2.0 × 8760 × 196.00 = BRL 3,433,920.00

Considering that in one year the revenue from the hybrid plant is 3,433,920.00 BRL and the initial investment is R$38,896,000.00, the investment will be returned in 12 years.

### 3.3. Project management

In order to execute a project with excellence and avoiding the incidence of errors, it is necessary to prepare a basic schedule. Considering this objective, a 2.0MW hybrid power plant was prepared based on the information that the operating company provided for the continuity and proof of this study, as shown in table 2.

*Table 2: Schedule for Implementation of the 2.0MW Hybrid Power Plant*

| Task | | DURATION (working days) |
|---|---|---|
| 1. | HR CONTRACTING | 254 |
| 2. | TECHNICAL VISIT | 252 |
| 3. | ENGINEERING | 125 |
| | Preliminary Projects | 38 |
| | Civil Project | 65 |
| | Planning | 22 |
| 4. | ACQUISITION AND SUPPLY | 60 |
| 5. | IMPLANTATION | 175 |
| | Preliminary services | 63 |
| | Photovoltaic Park | 135 |
| | Wind Farm | 120 |
| | Storage | 30 |
| 6. | CLOSURE AND REPORT | 98 |

*Source: (Authors, 2022)*

Table 2 shows a sample of activities that add up to more than 60 actions. Thus, the work would have a duration of 282 working days.

### 3.4. Mathematical Modeling

To perform the mathematical calculations, it was chosen the Google Sheets tool, aiming at dynamics, practicality and greater precision compared to conventional calculators. The first step was to filter the databases (as shown in Table 3), eliminating coordinates that did not meet one or more restrictions defined in topic 2.2. Then, with the help of the Google tool, tables were created with the remaining data, and the OR model was developed to find the optimal result.

In the computational model, the center of gravity formula was applied to the database of annual average solar irradiation (kWh/m²) of the northeastern states, obtaining the coordinates of *x* as -7.001944 latitude and *y* as -35.35127 longitude. In sequence, wind data (m/s) from the northeast of the country were manipulated, obtaining the results of *x* -6.193027 latitude and *y* -36.239455 longitude. To find the coordinate equivalent to the optimal point for the hybrid plant, the calculation of the midpoint between the two discovered points was used, with the final result found: -6.59749 latitude and -35.79536 longitude, as shown in Figure 4.

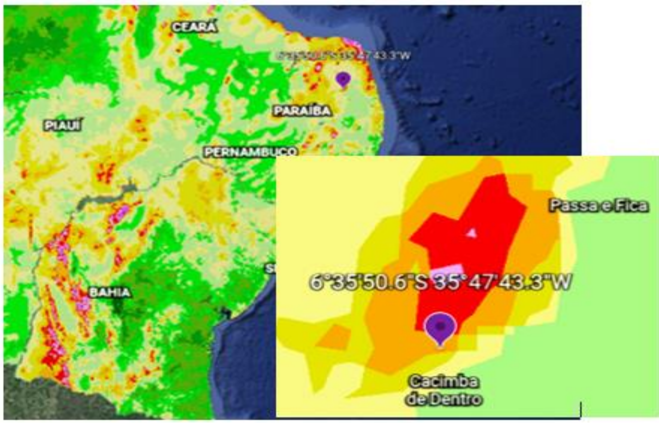
The optimal point generated by the formula of center of gravity combined with the midpoint, is located in the city of Cacimba de Dentro in the State of Paraíba, the nearest Substation is PILÕES II of CHESF - Companhia Hidro Elétrica do São Francisco. The relief of the area qualifies as a depression with tabular shapes, haracterized by being a monotonous, smooth-wavy relief.

*Table 3: Sample of 10 data Filtered Database for mathematical modeling*

| **LAT (X)** | **LONG (Y)** | **V_100m (velo. 100m)** | **Density $X_i$** | **Density $Y_i$** |
|---|---|---|---|---|
| -10.393.936,00 | -42.821.646,00 | 8,000120 | -83.152.735,2723 | -342.578.306,5975 |
| -3.915.293,00 | -38.969.638,00 | 8,000190 | -31.323.087,9057 | -311.764.508,2312 |
| -3.166.062,00 | -40.754.715,00 | 8,000470 | -25.329.984,0491 | -326.056.874,7161 |
| -10.393.936,00 | -43.056.524,00 | 8,000670 | -83.158.451,9371 | -344.481.039,8711 |
| -11.539.818,00 | -4.145.935,00 | 8,000890 | -92.328.814,4380 | -33.171.169,8822 |
| -9.336.198,00 | -42.023.059,00 | 8,001010 | -74.699.013,5600 | -336.226.915,2896 |
| -5.501.899,00 | -37.137.586,00 | 8,001010 | -44.020.748,9180 | -297.138.196,9619 |
| -5.457.827,00 | -37.137.586,00 | 8,001010 | -43.668.128,4053 | -297.138.196,9619 |
| -12.156.832,00 | -431.035,00 | 8,001170 | -97.268.879,4934 | -3.448.784,3110 |
| -3.386.424,00 | -42.492.816,00 | 8,001240 | -27.095.591,1658 | -339.995.219,0918 |

*Source: (Authors, 2022)*

*Figure 4: Optimal Point Superimposed on the Wind Database - zoom in and zoom out*




*Source: (Authors, 2022)*

Regarding the fiscal benefit parameter, the region has the Fain - The Paraíba Industrial Development Support Fund, which has the purpose of granting financial incentives for the implementation, expansion, revitalization and relocation of industry, granting presumed ICMS (taxes applied on services) credit with percentages varying between 48% and 74.25%. This variation occurs according to the number of direct jobs generated, volume of investments made, and the location chosen by the company. In addition to this fund co-managed by CINEP (Paraiba Development Company - *Companhia de Desenvolvimento da Paraíba*), there is also the SUDENE - Superintendence for the Development of the Northeast, which promotes investments made in projects in the energy sector, among the tax incentives granted by SUDENE there are a tax reduction of 75% for new projects and tax reinvestments.

## 4. Conclusion

With the constant creation of new climate goals for Brazil in order to reduce the emission of greenhouse gases by 50% by 2030 and neutralize carbon emissions by 2050, industries with clean and renewable energy are gaining notoriety. This work aimed to address possible improvements in the process of choosing the location and implementation of a hybrid power plant in northeastern Brazil, considering mainly the potential for generating wind and solar energy that the region has available. For this case, it was also necessary to understand the economic feasibility of the project, that is, what would be the Internal Rate of Return (IRR) to the investment, based on the topics of work, operation and maintenance. As a result, it was found that the necessary investment would be about 38,896,000.00 BRL, with a payback period of 12 years.

To validate the optimal point found through the application of the concepts and formula of the Operational Research, three important parameters were determined, namely: type of land, substation of the nearby concessionaire and tax benefits of the region. The resulting coordinates belong to the city of Cacimba de Dentro in the State of Paraíba, which has a land characterized by a depression with tabular shapes, that represents a monotonous and smooth-wavy relief. This area corresponds to a suitable region for the installation of the plant, as it does not present large undulations, thus not requiring large earthworks. The point is located relatively close to a substation, about 61 km away, being located in the city of Pilões-PB. Finally, the location also has tax incentives with FAIN - The Paraíba Industrial Development Support Fund granting presumed ICMS tax credit with percentages ranging from 48% to 74.25%, and SUDENE - Superintendence for the Development of the Northeast, also granting tax exemption (75% reduction in tax for new ventures) and tax reinvestments, which ends up enabling the installation of the hybrid plant. Thus, it is concluded that the optimal point satisfies all the criteria defined by the authors, and that the results obtained in this work prove the possibility of using this methodology for studies that require the ideal location for a given enterprise not necessarily linked to costs.

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