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**FEASIBILITY STUDY OF THE IMPLEMENTATION OF A SOLAR PHOTOVOLTAIC
POWER PLANT WITH SOLAR TRACKERS IN ITAJUBÁ, MINAS GERAIS**

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***Abstract.** In Brazil, the use of photovoltaic solar energy has been highlighted since the 70's. Starting in 2012, with ANEEL's normative resolution n° 482/2012, Brazilian consumers can generate their own electricity and supply the surplus to the energy distribution grids of their region. In this context, there is a constant search to develop technologies that optimize the efficiency to capture the solar radiation. The superior goal of this project is to study the viability of implementing a solar power station with 50 MW of installed capacity in the city of Itajubá (MG), using the most commonly technologies nowadays: the solar trackers. Such devices work guiding the solar panel in order to ensure the longest incidence of direct radiation, and it can be performed using of one or two orientation axes. In addition, this work going to comparatively evaluate the use of single axis solar trackers and two orientation axes in the plant. Then it going to validate the technology with better application feasibility in the region.*

***Keywords:** photovoltaic, solar tracker, technology*

1. INTRODUCTION

In recent years, the attention given to the new ways of producing energy has increasing, especially from renewable energy sources or from the optimization of traditional generation methods. Numerous technologies have been studied and implemented to capture the wind energy and the sun's energy. In this context, solar energy has been shown to be promising, whether for residential and industrial heating or for electricity generation using photovoltaic cells.

Innovations in materials and technologies have been assessed to make photovoltaic systems more efficient and accessible to the market. One way to increase efficiency is to provide better slope and orientation for the panels. The solar tracker is used precisely to adjust the panels as well as obtaining the best solar incidence throughout the day. These equipments can have one axis, which allows the solar tracking from east to west, or two axes, which adds the rotation from north to south (Sumathia and Kumar, 2017).

The city of Itajubá has sufficient incidence of sun for the use of this energy through photovoltaic panels. In addition, the use of solar trackers can improve the efficient utilization of the incoming solar rays by up to 45% (Passos, 2018). However, to make the implementation of a solar photovoltaic power plant of 50 MW viable in the municipality, it is necessary to make an economic analysis, evaluating the initial investment needed and the time of return. Likewise, for the implementation of solar trackers of one or two axes it is necessary to analyze the gain of energy in a year and to make a final economic analysis for the real implementation, because this technology increases a lot the value of the project investment.

2. METHODOLOGY

In order to validate the effect of the new technologies for the generation of electric energy by means of photovoltaic panels, the following case study was proposed: analysis of the generation of energy and economic viability of a 50 MW solar power plant in the municipality of Itajubá- MG, considering the impact of using different types of solar trackers. The Figure 1 shows the solar tracker of one axis used in the first case and the Figure 2 shows the solar tracker of two axes used in the second case.

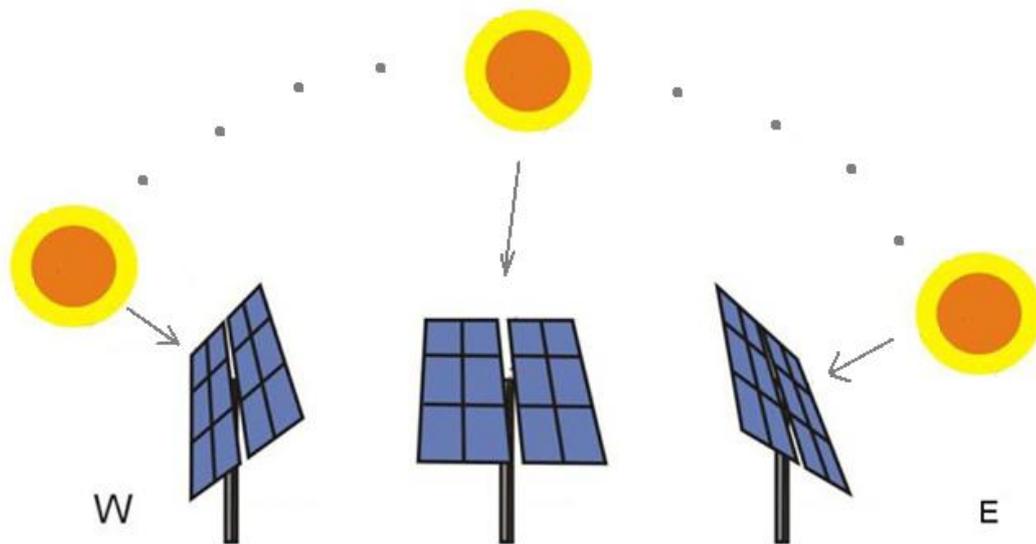


Figure 1 – Solar tracks of one axis



Figure 2 – Solar tracks of two axis

2.1 Considerations

Three types of solar panels with different power ratings will be considered for the calculations: 52% of 320 W, 45% of 325 W and 3% of 315 W. In total there will be 158,600 solar panels. The distribution mode of these panels (number of panels per strings) does not interfere with power generation calculation. It has been assumed that there is the MPPT (Maximum Power Point Tracking) technology at system, then the charge controller ensures that maximum power will be provided by the panels. The photovoltaic panels are always facing North, when located to the south of the Equator, with a slope equivalent to the latitude from where it is located as showed at Figure 3.

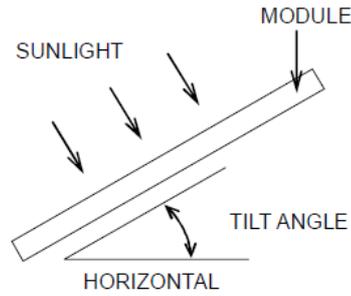


Figure 3 - Tilt equivalent to the latitude from where it is located: 23°

2.1.1 Sun Radiation

The direct radiation that can be used depends on the location of the photovoltaic plates. Currently there are several sources of radiation data such as SWERA, Sun Earth Tools and Solarimetric Atlases (Cardemil *et al*, 2010). For the purpose of analysis and comparison, this study report only the direct solar measure throughout the year as indicated in the experiments cited in the Minas Gerais Solarimetric Atlas made by Cemig (Energy Company of Minas Gerais), (Reis and Tibe, 2016). Direct solar radiation refers to the 15th day of each month and it is shown in Table1.

Table 1 - Average daily direct solar radiation of the city of Itajubá

Month	Daily direct solar radiation (kWh/m ²) ⁽¹⁾
January	4.230
February	4.690
March	4.490
April	5.250
May	5.340
June	6.140
July	6.220
August	6.460
September	5.030
October	4.760
November	4.270
December	3.850

⁽¹⁾ measured at the 15th day of every month

2.1.2 Degree of Solar Elevation

The degree of solar elevation represents the angular distance of the horizon to the Sun (Pianezzola, 2006). This parameter varies throughout the day according to the rotation of the Earth (reaching the maximum at midday solar), and throughout the year due to the translation movement. For the case studied, we consider the degree of elevation varying between 0° and 90° and 90° refers to when the sun hits is normal to the horizon (Júnior *et al*, 2012). The information is taken from Sun Earth Tools, which is a toolkit for solar energy designers and consumers. We considered the solar height for the 15th day of each month. The Figure 4 shows a model of degree of solar elevation.

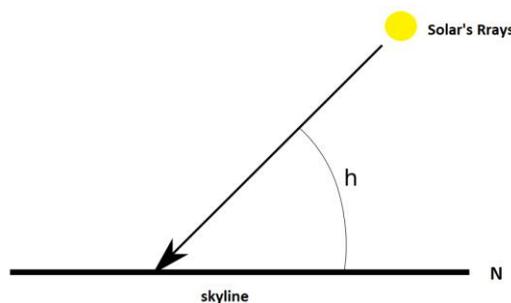


Figure 4 – Example of solar degree

2.1.3 Two-Axis Solar Tracker

In the case of a project in which solar trackers with two orientation axes are used, it is not necessary to make the correction of the radiation because the follower will always seek the best angle so that the direct radiation will be normal to the plates.

The amount of daily energy daily produced by the panels using solar trackers with two-axis, E_{2axes} can be obtained by the Equation 1 (CSI, 2018). R is the direct local radiance of the calculated day, η_{panel} is the photovoltaic panel efficiency and A_{panel} is the photovoltaic panel area.

$$E_{2axes} = R * \eta_{panel} * A_{panel} \quad (1)$$

2.1.4 Single-Axis Solar Trackers

For cases where there is no use of solar trackers, or there is only use of single-axis solar trackers, it is necessary to apply a correction factor for direct solar radiation. In the case of the follower of one axis, the incident radiation must be corrected according to the variation of the solar height every month, since the slope adopted by the panels, θ_{panel} will be constant throughout the year. From Junior *et al* (2012) it is known that this slope of the panels should be equal to the latitude of the region where is located, so that the project can provide a greater use of energy throughout the year.

This correction factor was obtained empirically and Equation 2 gives the value of the energy produced by solar panels using solar trackers of one single axis number of day. h_{max} is the maximum solar elevation in day (it was used the maximum solar height of the 15 day of each month).

$$E_{1axis} = R * \cos(90^\circ - \theta_{panel} - h_{max}) * \eta_{panel} * A_{panel} \quad (2)$$

2.2 Power Generation of the Plant

The Equations 3 and 4 provides the energy produced monthly, E_{month} , and annually, E_{annual} , by the plant is the number of panels and is the amount of days in a month.

$$E_{month} = n * d * E_{x axes} \quad (3)$$

$$E_{annual} = \sum_{Jan}^{Dec} E_{month} \quad (4)$$

2.3 Economic Analysis

The economic analysis of each project will conclude the feasibility of the proposed technologies in an investment project. This analysis consists of the elaboration of a cash flow with the inflows and outflows of cash expected to happen during the economic life of the project, and the application of the Net Present Value (NPV) and Internal Rate of Return (IRR) methods. These methods are equivalent and always indicate the same investment alternative, which is the best from the economic point of view.

The evaluation methods that will be used have as main characteristic the recognition of the variation of the value of money over time. This fact evidences the need to use an interest rate when the analysis is performed through one of them. The Minimum Rate of Attractiveness (TMA) is the rate at which the investor believes that is making financial gains. In other words, an investment proposal to be attractive should yield at least this interest rate (Oliveira, 1982).

2.3.1 Project Variables

Table 2 shows the variables and values considered in the economic analysis of the project. Value of the investment, percentage of financing. These variables are divided into three groups: financing variables, energy production variables and cost variables.

Table 2 - Values adopted in the economic analysis

Total investment (R\$)	200,000,000.00
Private fund (R\$)	60,000,000.00
Financing (R\$)	140,000,000.00
Power of the panels (W)	325W; 320W; 325W
N°of panels	594,750
Pot Inst (kW)	50,000
Rate (R\$ / kWh)	0.29858
Capital Entry (R\$)	27,090,808.47
Inflation (%)	7.00%

Taxes (R\$)	34%
Interest (R\$)	0.9%
Depreciation of equipment (%)	5%

The financing variables are the value of the total investment, representing the sum of the private equity capital and the financing capital. The total estimated investment was R \$ 200,000,000.00 using solar single-axis trackers. In addition, it is considered a financing of 70% of the value (BNDS, 2018). The value of initial investment using solar trackers with two orientation axes will vary in a sensitivity analysis, increasing the value of a single -axis investment from 10% to 100%.

The production variables includes the types of and the number of panels and the amount of money earned by the venture. The energy tariff adopted was 0.30 R\$/kWh (BNDS, 2017). The cash inflow shows the amount collected by the generated energy minus the losses and stops.

The cost variables are inflation of 6.87% (Penafiel, 2011), 0.9% of interest and 5% of depreciation per year for a twenty-year accounting life (BNDS, 2018).

2.3.2 Cash Flow

The cash flow will record the inflows and outflows of cash annually, as well as the pending funding. The costs of maintenance, insurance, administrative expenses, payment of the financing through constant amortization system (SAC) and interest on financing will be subtracted from the value of the admission. Subtracted from expenses, the accounting profit is calculated for income tax purposes, considering the depreciation of the plates.

2.3.3 Net Present Value (NPV) and Internal Return Rate (IRR)

The NPV and the IRR will be calculated from the cash flow and a 20% minimum acceptable rate of return (Penafiel, 2011). These values will be compared for each initial investment value for two-axis solar tracker.

3. RESULTS

3.1 Single-Axis Solar Trackers

3.1.1 Energy Generated

Table 3 shows the energy produced by the plant using single axis solar tracker.

Table 3 - Energy produced by each type of solar panel for the project using single axis solar tracker

Month	Number of days	Energy Produced (kWh/month)		
		315 W	320 W	325 W
January	31	20,4045.506	326,0151.454	2,851,875.837
February	28	212,126.922	3,389,272.848	2,964,827.087
March	31	229,626.868	3,668,879.465	3,209,417.980
April	30	256,016.189	4,090,516.702	3,578,252.700
May	31	258,331.057	4,127,502.655	3,610,606.824
June	30	279,155.634	4,460,228.812	3,901,664.985
July	31	296,177.058	4,732,189.811	4,139,567.737
August	31	320,871.139	5,126,741.224	4,484,708.647
September	30	248,763.529	3,974,636.808	3,476,884.688
October	31	240,924.313	3,849,385.179	3,367,318.584
November	30	201,647.218	3.221,832.632	2,818,355.761
December	31	183,485.600	2,931,654.100	2,564,516.896
Total	365		90,732,160.452 ⁽¹⁾	

(1) Total in year

3.1.2 Cash Flow

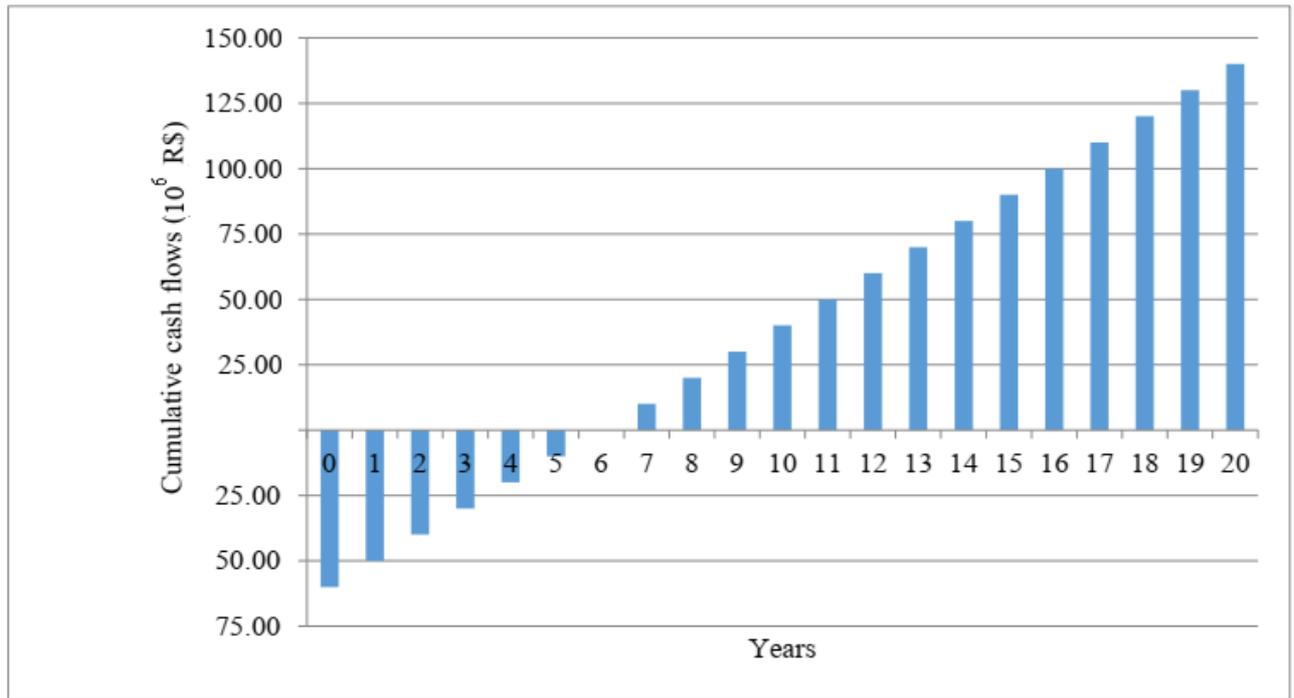


Figure 5. Cumulative cash flow for the project using single axis solar tracker.

3.1.3 Net Present Value (NPV) and Internal Return Rate (IRR)

In Table 4 is reported the IRR and the NPV obtained in the analysis of the case.

Table 4 - Internal rate of return and net present value for the project using single axis solar tracker

IRR (%)	48.20
NPV (R\$)	103,264,570.57

3.2 Two-Axis Solar Tracker

3.2.1 Energy Generated

Table 5 shows the energy produced by the plant using panels with a two orientation axis.

Table 5 - Energy produced by each type of solar panel for the project using two axis solar tracker

Month	Number of days	Energy Produced (kWh/year)		
		315 W	320 W	325 W
January	31	216,429.326	3,458,014.797	3,024,960.337
February	28	216,742.920	3,463,025.266	3,029,343.335
March	31	229,732.310	3,670,564.170	3,210,891.706
April	30	259,952.862	4,153,415.164	3,633,274.256
May	31	273,222.837	4,365,437.119	3,818,744.256
June	30	304,021.061	4,857,517.926	4,249,200.748
July	31	318,248.323	5,084,834.997	4,448,050.425
August	31	330,528.001	5,281,034.418	4,619,679.380
September	30	249,059.599	3,979,367.291	3,481,022.763

October	31	243,546.948	3,891,288.518	3,403,974.280
November	30	211,428.328	3,378,111.000	2,955,063.061
December	31	196,986.502	3,147,365.713	2,753,214.491
Total	365		94,407,294.435	

3.2.2 Cash Flow

The cash flow obtained for the project using two-axis solar tracker is shown in Figure 2, varying the investment increment from 0% to 100%

3.2.3 Net Present Value (NPV) and Internal Return Rate (IRR)

The Table 6 shows the NPV and IRR of the enterprise with two orientation axes considering variation of these values as the initial investment increases. The Figure 6 shows the sensitivity variation IRR curve and the Figure 7 shows the sensitive NVP curve.

Table 6 - Internal rate of return and net present value for the project using a two axis solar varying the investment increment from 0% to 100%

Increment (%)	IRR (%)	NPV (10 ⁶ R\$)
10.00	45.4%	101.23
20.00	43.0%	99.19
30.00	40.9%	97.15
40.00	39.2%	95.11
50.00	37.6%	92.98
60.00	36.1%	90.40
70.00	34.7%	87.41
80.00	33.4%	84.11
90.00	32.1%	80.57
100.00	31.0%	76.87

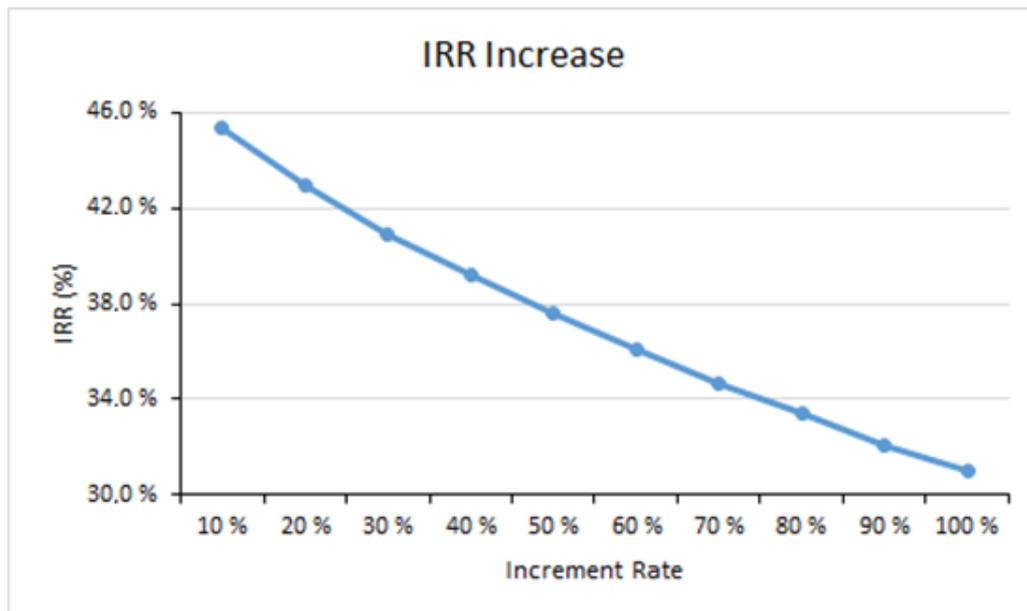


Figure 6. Internal rate of return for the project using a two axis solar varying the investment increment from 0% to 100%.

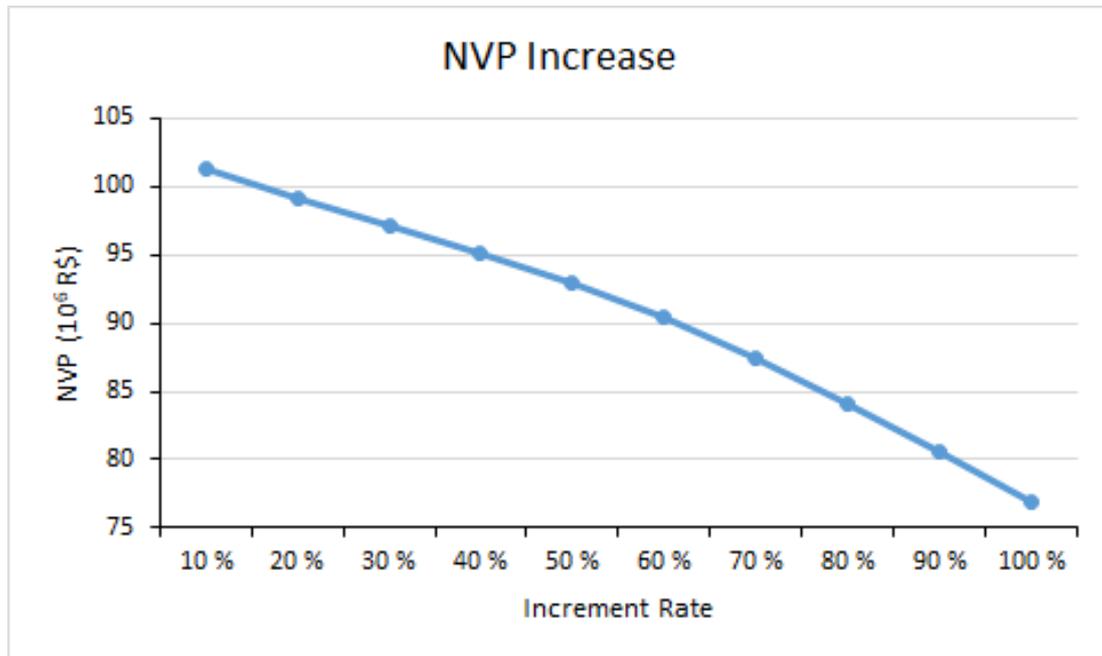


Figure 7. Net present value for the project using a two axis solar varying the investment increment from 0% to 100%.

3.3 Comparison

Table 7 shows the power generation in a year of the power plant using solar trackers of one and of two axes, but disregarding the increase in investment. The Figure 8 this comparison.

Table 7 - Power generation by the solar photovoltaic power plant

Solar Tracker	Power generation	Increased generation
One axis	90,732.160 MWh/year	0.00%
Two axes	94,407.294 MWh/year	4.05%

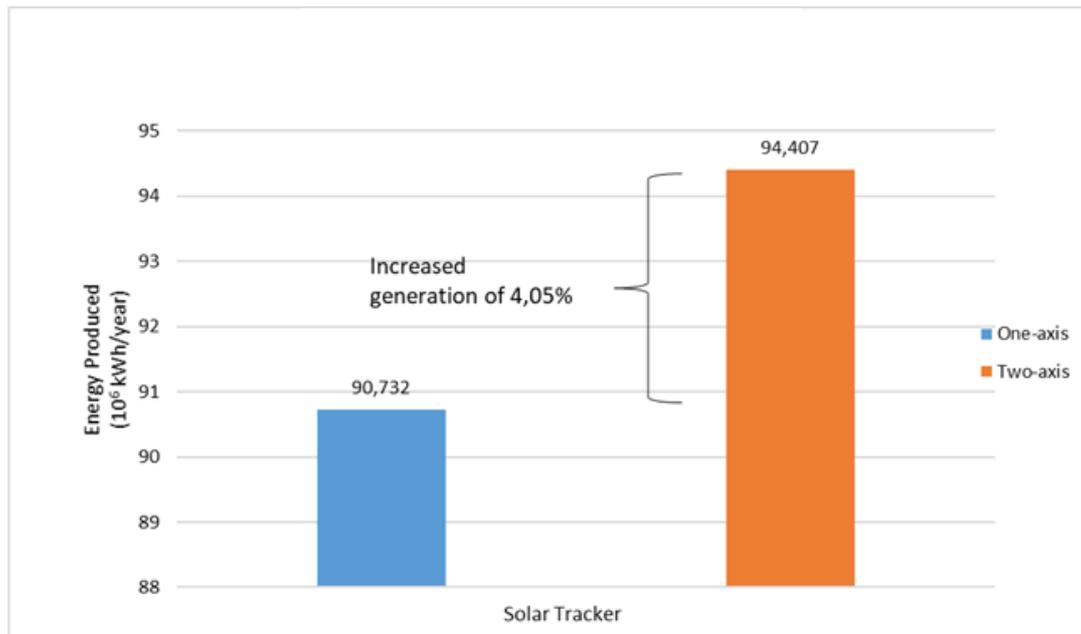


Figure 8 – Energy produced by the solar photovoltaic plant

4. CONCLUSION

The economic analysis and the comparison of the projects shows that the implantation of a photovoltaic solar power plant with simple solar tracker of a single axis, in the municipality of Itajubá, is technically feasible. This is because the NPV and the IRR of the analysis were positive and higher than the Minimum Attractiveness Rate, respectively. On other hand, the analysis of solar tracker of two axes, due to its high complexity in relation to single axis solar tracker, shows an increase in electric power generation less than 5% in a year. It must be emphasized that the case studied was to latitude of approximately 22 ° S. This is a location situated relatively close to the Equator Line because it is between the Tropic of Cancer and the Tropic of Capricorn. This makes the energy generation less sensitive to variations in solar height throughout the year, as opposed to regions farther away from the Equator. In addition, the increase in the initial investment also influences the technology to be less attractive in relation to the benefit, by reducing its NVP and IRR. Therefore, from analyzes performed, the implementation of the solar trackers of two axes will fall drastically when costs as maintenance are inserted in the cash flow. Considering a comparison between the two technologies, in those circumstances, the single axis solar tracker shows to be the most attractive. These technologies can be improved in the future, so this technology can be revised due to the technological evolution and the cost reduction.

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