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Comparative analysis of the economic feasibility of photovoltaic and wind systems for microgeneration

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ABSTRACT

The present work presents a comparative study of economic feasibility analysis and decision criteria for choosing distributed microgeneration systems of electric energy between photovoltaic systems and wind turbines, based on the methods of Net Present Value (NPV), Internal Rate of Return (IRR), and Equivalent Annual Cost (CAE). It is known that today the financial amount of investment in distributed microgeneration systems is considered to be of great magnitude and if it is not well evaluated, the project may have compromised capital return rates. Therefore, the selection criteria in the investment opportunities within the electric power generation options between the two mentioned systems are shown. Several economic scenarios are studied to determine which option is more viable between photovoltaic generation and wind turbines for a power of up to 5MW, which characterizes distributed microgeneration, according to ANEEL Normative Resolution 687/2015.

Keywords: Photovoltaic, Wind Turbines, Economic Viability.

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INTRODUCTION

The National Electric Energy Agency (ANEEL), through its thematic booklet, characterizes distributed generation as the installation of small generators, usually from renewable sources, located close to electricity consumption centers. In general, the presence of small generators close to the loads can provide several benefits for the electrical system, among which the postponement of investments in expansion in the distribution and transmission systems stand out; the low environmental impact; the improvement of the grid voltage level in the period of heavy load and the diversification of the energy matrix. Distributed microgeneration refers to an electric power generating plant, with an installed capacity of less than or equal to 75 kilowatts (kW), while distributed minigeneration refers to generating plants with an installed capacity greater than 75 kW and less than or equal to 3 megawatt (MW), for the hydro source, or 5 MW for other sources. (ANNEL, 2016).

The predominance of renewable sources in the Brazilian energy matrix should remain stable in 2017, with a share of 43.8% of the total. The performance reflects the transformations that have occurred in the national energy sector, which has encouraged both the growth of these sources and the diversification of the matrix in recent years. The data are contained in the Monthly Energy Bulletin – January 2017, prepared by the Ministry of Mines and Energy.

According to ABSOLAR - Brazilian Association of Photovoltaic Solar Energy, an entity that represents the photovoltaic solar energy sector in the country, there is a great expectation that Brazil will reach the mark of 1GW in installed capacity in photovoltaic solar energy plants this year, a number registered in just over twenty countries. Expectations could be even higher, since solar energy auctions held by the country since 2014 predicted almost 2 GW in operation by August 2017. Despite the setbacks, the country has a lot of future investing in solar energy. In addition to the growth through large plants, Brazil's potential for the installation of solar panels on roofs has been gaining prominence in the market, a segment in which the number of supporters has skyrocketed, with an increase of more than 300% in 2016. In 2017, even greater growth is expected due to the drop in the price of equipment.

The value of a project depends on its ability to generate future cash flows, i.e., its potential to generate economic income. Thus, investment alternatives can be compared only if the monetary consequences are measured at a common point in time, and, since investment or financing operations are characterized by a spacing of cash flows over time, economic evaluation criteria should consider their updating. Among the decision criteria in the analysis and evaluation of capital investments, the results of the Net Present Value (NPV), Internal Rate of Return (IRR) and Equivalent Annual Cost (CAE) methods will be compared.

Through the regulation by PRODIST (Module 3) and later by ANEEL Resolutions 487/2012 and 687/2015, and the subsequent technical standards of the energy concessionaires in December 2012, regularizing the connection of distributed Micro and Minigeneration customers within the energy compensation systems, a growing diffusion of photovoltaic generation in Brazil is expected.

METHODOLOGY

The fundamental concepts of each actuarial method used in this work will be presented, accepted to measure profitability, and then the analysis of the economic viability of the investment alternatives will be made. In the analysis of alternative investments in projects, it should be borne in mind that there is always a Minimum Attractiveness Rate (MAT) that will serve as a reference for decision making. This rate corresponds to the interest rate available in the financial market and is what you want to earn at least when making an investment. The problem is that there is no formula for calculating the MAT, however, some criteria must be analyzed (Riba et al, 2012): profitability, degree of risk and security of the investment, liquidity, local investment scenario (political and economic stability) and inflation.

Thus, a TMA that can be used is the IPCA (Consumer Price Index) yield. However, it should be remembered that the TMA depends on the sector you are working in and the associated risk. Therefore, for any investment to be attractive, it must have a yield higher than the chosen reference rate, otherwise, in addition to losing, there would be concern about unnecessary risks (purchase, transportation, installation and maintenance). The TMA is the soul of any investment analysis, so the TMA of i*=6.28% per year, which is the IPCA rate accumulated in 2023, will be considered in this work.

NET PRESENT VALUE (NPV) METHOD

The net present value (NPV) method aims to calculate in terms of present value, the impact of future events associated with an investment alternative. That is, it measures the present value of the cash flows generated by the project over its useful life. If there is no capital restriction, it is argued that this criterion leads to the optimal choice, as it maximizes the value of the project (Samanez, 2010). A Eq. (1) shows the expression that defines the NPV, where the decision criterion will be $NPV > 0 \Rightarrow$ economically viable project.

$$VPL = -I + \sum_{t=1}^{n} \frac{FC_t}{(1+k)^t} \quad (1)$$

The FCt represents the cash flow in the t-th period, I the initial investment, k is the cost of capital, and the symbol $\sum$, sum, indicates that the sum of the cash flows discounted to the initial period must be carried out from date 1 to date n. The deciding rule to be followed when applying NPV is: undertake the project if the NPV is positive.

The goal of NPV is to find investment alternatives that are worth more than they cost to sponsors, alternatives that have a positive net present value.

INTERNAL RATE OF RETURN (IRR) METHOD

The internal rate of return (IRR) method is not intended to evaluate absolute profitability at a certain cost of capital (update process), such as NPV; but aims to find an intrinsic rate of return. By definition, IRR is a rate of return on investment (Samanez, 2010). Mathematically, the IRR is a hypothetical rate that cancels out the NPV, that is, it is that value of i* that satisfies the following equation:

$$VPL = -I + \sum_{t=1}^{n} \frac{FC_t}{(1+k)^t} = 0 \quad (2)$$

The decision criterion: whether i* $>$ k $\Rightarrow$ economically viable project. The decision-making rule to be followed in the IRR method is to undertake the investment project if the IRR exceeds the opportunity cost of capital. Essentially, the method asks: Does the expected rate of return on the investment project exceed the required rate of return? Will the project create value? At first it seems the same thing as the NPV rule, but this is not always true.

EQUIVALENT UNIFORM ANNUITY (EUU) METHOD

In order to compare different alternatives for the application of capital from different projects, it is necessary that these alternatives are comparable. Therefore, the investment study should be carried out within a uniform planning horizon so that the projects can be compared. Although it is a useful tool for evaluating investment alternatives, NPV does not answer all questions about the economic advantage of an alternative over another that has a different expected duration, as is the case with the alternatives studied here.

The method consists of equalizing the economic horizons at some future date, corresponding to the minimum common multiple of the terms of the alternatives. This procedure is called the chain rule. However, when there are very durable alternatives, such as photovoltaic panels (25 years) and wind turbines (15 years), an alternative and more practical method is the equivalent uniform annuity (EUA). This indicator shows how the economic income generated by the project would be distributed if this distribution were equitable for each year, which is equivalent to spreading the NPV over the life of the project, transforming it into an equivalent uniform series, which can be legitimately compared between projects of different duration.

The equivalent annuity can be calculated by the ratio of the Net Present Value (NPV) and the uniform series present value factor (an,k%), i.e.:

$$AE = \frac{VPL}{a_{n,k\%}} = \frac{VPL}{\left[\dfrac{(1+k)^n - 1}{(1+k)^n \times k}\right]} \quad (3)$$

Where:

an,k% = present value factor of uniform series;

k = cost of capital; and

n = term of the alternative.

The alternative that creates the most value per unit of time is chosen. The equivalent annuity method does not explicitly repeat alternatives like the process of successive substitutions, but does so implicitly. In other words, the method assumes that the alternatives will be replaced by identical ones at the end of their term. This assumption may be reasonable, and will have some consistency, if the dynamics of technological changes in equipment are slow and the other conditions are met (Samanez, 2010).

EQUIVALENT ANNUAL COST (CAE) METHOD

In certain projects, the benefits or revenues can hardly be qualified in monetary terms, however, the costs can be. If there are alternatives that produce the same service, qualifying or not, but at a different cost, the revenue or benefit may be known, since, as it is a common factor to all alternatives, it will be irrelevant in an incremental analysis. Thus, in these cases, it would be enough to know the costs of the alternatives and select the one with the lowest annualized costs.

Often, in economic engineering problems, it is easier to determine cost streams than revenues. As in our example, if the problem is to select between the two distributed microgeneration systems, photovoltaic or wind turbines, it will be easier to raise the costs per kilowatt/hour than to estimate revenues.

The equivalent annual cost (CAE) is basically a uniform apportionment, per unit of time, of the investment, opportunity and operational costs of the alternatives. When you have the opportunity to compare technological alternatives, you take into account the initial investment, the useful life and the cost of capital. The equivalent annual cost is the ratio of the investment in the equipment or project to the uniform serial present value factor.

$$CAE = \frac{I}{a_{n,k\%}} = \frac{I}{\left[\frac{(1+k)^n - 1}{(1+k)^n \times k}\right]} \quad (4)$$

Where:

I = Investment;

$a_{n,k\%}$ = uniformly serial present value factor;

k = cost of capital; and **n** = term of the alternative.

DISCOUNTED PAYBACK METHOD (PB)

We often need to know the payback time of an investment, i.e., how many years will elapse until the present value of the forecasted cash flows equals the initial investment. If I represents the initial investment, FCt the cash flow in period t, and k the cost of capital, the payback method consists of determining the value of T and k in the equation below:

$$I = \sum_{t=1}^{T} \frac{FC_t}{(1+i^*)^t} = \frac{FC_1}{(1+k)^1} + \frac{FC_2}{(1+k)^2} + \ldots + \frac{FC_T}{(1+k)^T} \quad (5)$$

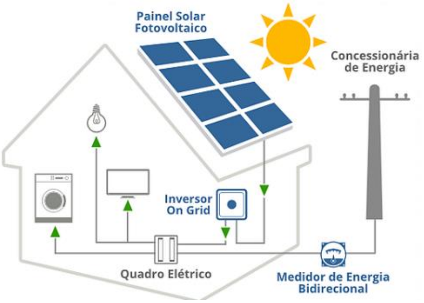
This indicator is used in conjunction with the NPV or IRR methods for decision making.

SOLAR PHOTOVOLTAIC ENERGY SYSTEMS

A "Solar Photovoltaic System" refers to an electricity generator whose primary source of energy is solar radiation. PV systems can be classified as isolated, hybrid, and connected to the power grid. The latter is the object of our research, since they are interconnected to the energy utility grid, they do not require energy storage, as the energy not consumed is delivered to the large electrical system to which it is connected, and the grid acts as a large virtual battery. The entire arrangement is connected to frequency inverters and then connected to the grid, as shown in Fig. 1. Inverters must meet quality and safety requirements so that the grid is not affected (Lopez, 2012).

Solar systems connected to the electricity grid form a small plant whose electricity can be used by the producer or other facilities connected to the grid, as determined by the possibilities listed in the RES. ANEEL 687/2015. These systems become part of the interconnected power grid and when there are power interruptions by the utility, the photovoltaic system is shut down for safety measures, avoiding the energization of a grid under maintenance.

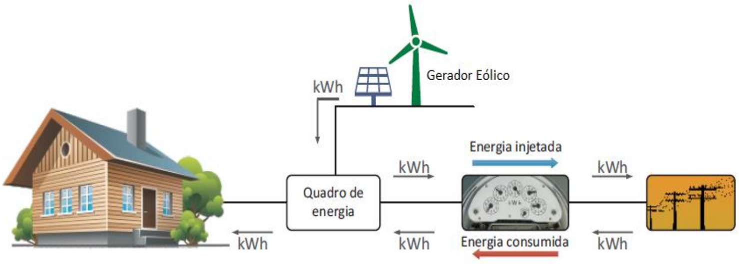
Figure 1 – Schematic drawing of the photovoltaic system connected to the grid (Source: GreenSun, 2017).



WIND ENERGY SYSTEMS WITH HORIZONTAL WIND TURBINES

"Wind Generators" are machines capable of transforming the kinetic energy of the winds into electrical energy. Kinetic energy is converted into rotational mechanical energy by the wind turbine. This mechanical energy is transmitted by the shaft through a gearbox or directly to the generator, which performs the electro-mechanical conversion, producing electrical energy. Fig. 2 shows the configuration of a hybrid system, contemplating the insertion of a wind generator. The electricity generated can be injected directly into the conventional power grid or used in isolated systems. In the composition of the calculation of investment and cost in this form of energy, several factors are taken into account, such as the estimated annual production, interest rates, construction costs, maintenance, location and the risks of generators falling. Therefore, the calculations on the real cost of producing wind energy differ greatly, according to the location of each plant.

Figure 2 – Schematic drawing of a hybrid system with photovoltaic and wind generation (Source: ANEEL, 2016).



COST OF ELECTRICITY PRODUCTION BY PHOTOVOLTAIC AND WIND SYSTEMS

COST OF PHOTOVOLTAIC ENERGY

Brazilian economic growth imposes a growing demand for energy. The improvement in the quality of life of the population has been achieved with the evolution of the income of a large part of the Brazilian population in recent years, enabling access to basic infrastructures such as housing, sanitation and transportation.

The price of solar energy, which eliminates the need for complex transmission and distribution systems, is calculated and compared with the amount paid by final residential consumers, instead of being compared with the price offered by the generating plant. The cost of implementing solar generation can reach 50 times the cost of a small hydroelectric plant, however the cost of energy generated during the useful life of the system, of approximately 30 years, is 10 times higher for isolated systems and 3 times higher for generation interconnected to the electric grid. With the annual reduction in the cost of solar systems and the valuation of the environmental and social costs of centralized generation, the solar system tends to become economically competitive in the short term (Shayani et al, 2006).

Shayani et al (2006) considered that the modules of photovoltaic systems invariably have a period of 25 (twenty-five) years of warranty given by the manufacturer, and 5 (five) years of useful life can be added, making a period of 30 (thirty) years as the useful life expectancy of photovoltaic panels. The other equipment in the photovoltaic system has approximately the following useful life periods, as estimated by the manufacturers: 5 years for battery banks, when the system is isolated, and 10 years for charge controllers and frequency inverters. Thus, the cost of a photovoltaic system for 30 years takes into account the initial value of the equipment and its replacements at the end of its useful life: 1 × cost of the solar panel, 2 × cost of the frequency inverter, 1 × cost of support (support hardware), 2 × cost of the electrical panel, 2 × cost of cabling and connectors. The price of a 2 kWPico photovoltaic system is shown in table 10, quoted in October 2017. The selected configuration is standard and presents the best cost-benefit, as the number of panels is sized to make the most of the energy conversion in the frequency inverter, thus reducing expenses due to oversizing. The cost of this system, to generate energy for a power of 2.12 kWp, is shown in table 1. It is worth mentioning that the cost of installation is not taken into account due to regional aspects that are difficult to measure for each region.

Table 1 – Cost of installing a 2.12 kWPico photovoltaic system*

Qty	Item	Unit Price [R$]	Total Amount [R$]
8	Photovoltaic Panels, 265 Wp	624.00 (R$ 2.35/W)	4.992,00
1	Frequency Inverter, 2140 W	5.034,00	5.034,00
1	8-Panel Bracket Kit	1.678,00	1.678,00
1	Electrical Switchboard (Stringbox)	1.290,00	1.290,00
30	meters from Cabo Solar	4,00	120,00
2	MC4 Connector Pairs	23,80	47,60
	Total Amount: R$ 13,161.60		

*Amounts collected on the internet on 10/25/2017.

It should be noted that this value from R$ 13,161.60 to 2.12 kWp presents a ratio of 6.20 R$/W, which corresponds to approximately 4.47 US$/W, considering the dollar of the day at R$ 3.24. Thus, the quoted value is below the typical value used, this is due to the scale production that the photovoltaic panels are being produced.

As a useful life of 30 (thirty) years is expected for the photovoltaic system, table 2 shows the projection estimate for this period.

Table 2 – Estimated cost of the photovoltaic system for 30 years

Qty	Item	Cost [R$]
	1 × Painel	4.992,00
	2 × Frequency Inverter	10.068,00
	1 × Suporte Kit	1.678,00
	2 × Electrical Panel	2.580,00
	2 × Cabo Solar	240,00
	2 × Connectors	95,20
	Total: R$ 19.653,20	

Another important factor to take into account is the efficiency of the system, composed of external factors inherent to the system, such as: shading, dirt, power tolerance, temperature, cabling and energy conversion. The acceptable average of these losses is 50% (Tiba, 2000), so you can recalculate the energy generated per day:

- Energy Generated = Power × Hours of Sunshine/day × Yield = 2.12 kW × 5 h × 0.50 = 5.3 kWh/day.
- In 30 years, this energy corresponds to: 5.3 kWh/day × 365 days × 30 years = 50,035 kWh = 50.035 MWh.
- Thus, the total cost versus energy generated ratio will be: R$ 13,161.60/50.035 MWh = 263.05 R$/MWh.
- Applying the same methodology to several powers, the statement between the monetary cost for the intended power was obtained, which is shown in table 3.

Table 3 – Statement of the cost for various powers of Photovoltaic Systems*

Power [kWp]	Annual Cost [R$]
2,12	13.161,60
2,92	15.719,02
3,12	20.509,00
3,38	21.609,55
4,77	29.181,64
5,83	34.647,51
6,89	40.278,63

*Amounts collected on 10/25/2023 on the internet.

COST OF WIND ENERGY

For wind energy to be considered technically usable, its density must be greater than or equal to 500 W/m² at a height of 50 m, which requires a minimum wind speed of 7 to 8 m/s (Lopez, 2012). In Brazil, the price of wind energy is around R$ 99.58/MWh, making it cheaper than natural gas-fired thermoelectric power. In the last auction, more than 1,900 MW were sold, an amount higher than the total wind energy installed in the country so far. Thus, the production of wind energy in the country will more than double by 2017, the year of completion of the projects sold in the auction. The fall in the price of steel, which is important for the production of wind turbines, may also serve as an incentive in the short term. Another factor that has led to this strong growth is the consolidation of an industry specialized in wind generation. Despite using the technology already consolidated in the traditional generations, hydroelectric and thermal, some adaptations must be made, as the rotation speed of the turbines is much lower than that of the traditional generation, with the wind speed varying in the range of 5 to 25 m/s, for the heights of the turbines that exist today.

The systems studied here, photovoltaic and wind, have the same configuration, differing only with the addition of the wind turbine, as shown in figures 1 and 2, respectively. Thus, in the pricing of the second system, the same prices of photovoltaic systems will be considered, replacing only the cost of the panels. Following the same methodology used in the previous item, the wind system can be priced as follows:

Table 4 – Cost of installing a 2 kWPico Wind System*

Qty	Item	Unit Price [R$]	Total Amount [R$]
1	Wind turbine, 2 kWp	10.290,00 (R$ 5,145/W)	10.290,00
1	Frequency Inverter, 2140 W	5.034,00	5.034,00
1	Electrical Switchboard (Stringbox)	1.290,00	1.290,00
30	Cabo Solar Meters	4,00	120,00
	Total Amount: R$ 16,734.00		

*Amounts collected on the internet on 10/25/2023.

It is verified that the value of R$ 16,734.00 for 2 kWp presents a ratio of 8.36 R$/W, which corresponds to approximately 3.80 US$/W, considering the dollar of the day at R$ 3.24. Thus, the quoted value is compatible with the typical value used.

It was considered that the wind turbine of wind systems has a period of 15 (fifteen) years of warranty given by the manufacturer. The other equipment in the wind system is the same as the photovoltaic system and the same useful life periods were considered, according to manufacturers' estimates: 10 years for charge controllers and frequency inverters. Thus, the cost of the wind system for 15 years takes into account the initial value of the equipment and its replacements at the end of its useful life: 1 × cost of the wind turbine, 1 × cost of the frequency inverter, 1 × cost of the electrical panel, 1 × cost of cabling and connectors. The price of a 2 kWPico photovoltaic system is shown in table 5, quoted in October 2017. As a useful life of 15 (fifteen) years is expected for the wind system, table 5 shows the projection estimate for this period.

Table 5 – Estimated cost of the Wind system for 15 years

Item	Cost [R$]
1 × Wind Turbine	10.290,00
1 × Frequency Inverter	5.034,00
1 × Electrical Panel	1.290,00
1 × Cabo Solar	120,00
Total: R$ 16.734,00	

The theoretical maximum that a wind turbine can extract is 0.59 (i.e. no more than 59% of the wind energy can be extracted by a wind generator). But when you add a few more engineering requirements - mainly strength and durability - the actual values achieved are well below the Betz limit with values between 0.35 - 0.45 being used even among the best designed wind turbines. If we add to this other inefficiencies of the entire system of a wind generator - the wind turbine, transmission, inverter, etc. - only about 10-30% of wind energy is converted into electrical energy that can be used.

- Energy Generated = Power × Operating Hours/Day × Yield = 2 kW × 20 h × 0.30 = 12 kWh/day.
- In 15 years, this energy corresponds to: 12 kWh/day × 365 days × 15 years = 65,700 kWh = 65.7 MWh.
- Thus, the total cost versus energy generated ratio will be: R$ 16,734.00/65.7 MWh = 254.70 R$/MWh.

RESULTS AND DISCUSSIONS

The procedural analyses applied in both photovoltaic and wind systems deal with the various methods and criteria to indicate which system is more profitable during its useful life. The cash flow in each year refers to the twelve monthly invoices that make up the annual disbursement, the investment in each system is configured in the market prices charged by them. The analyses were made for power of 2 kWp, initial investment of R$ 19,653.20 for the photovoltaic system, R$ 16,734.00 for the wind system as shown by the pricing in the previous item, applying an energy inflation of 10% p.a. It is worth mentioning that this percentage that was admitted is below the percentage practiced by the energy concessionaires due to the application of tariff flags. Table 6 shows the simulated data in the EES (Engineering Equation Solver) platform for the Capital Flow, NPV, IRR and AE for the two systems taking the above values as input data.

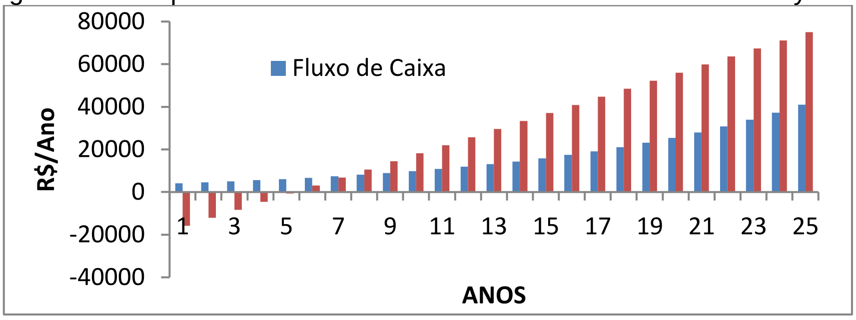
Table 6 – Data obtained from simulation in EES Platform

Years	Both Systems. FC [R$/year]	Last. Solar NPV [R$/Year]	Last. Solar SHOOTING [%]	Last. Solar CAE[R$/Year]	Sist. Wind NPV [R$/Year]	Sist. Wind SHOOTING [%]	Sist. Wind CAE[R$/Year]
1	4164	-15869	-0,7881	-1748	-12949	-0,7512	-1702
2	4580	-12083	-0,3869	-1331	-9163	-0,591	-1205
3	5038	-8298	-0,1206	-914,1	-5378	-0,04919	-707
4	5542	-4512	0,04997	-497,1	-1592	0,1228	-209,3
5	6097	-726,7	0,1667	-80,06	2193	0,2401	288,4
6	6706	3059	0,2531	337	5979	0,3275	786
7	7377	6844	0,3222	754	9764	0,3987	1284
8	8114	10630	0,3818	1171	13550	0,4616	1781
9	8926	14415	0,4367	1588	17335	0,5212	2279
10	9818	18201	0,4903	2005	21121	0,5807	2777
11	10800	21986	0,5449	2422	24906	0,6427	3274
12	11880	25771	0,6024	2839	28691	0,7088	3772
13	13068	29557	0,664	3256	32477	0,7805	4270
14	14375	33342	0,7311	3673	36262	0,8589	4768
15	15813	37128	0,8044	4090	40048	0,9449	5265
16	17394	40913	0,885	4507	------	------	------
17	19133	44699	0,9735	4924	------	------	------
18	21047	48484	1,071	5341	------	------	------
19	23151	52270	1,178	5758	------	------	------
20	25467	56055	1,296	6175	------	------	------
21	28013	59841	1,425	6593	------	------	------
22	30815	63626	1,568	7010	------	------	------
23	33896	67411	1,725	7427	------	------	------
24	37286	71197	1,897	7844	------	------	------
25	41014	74982	2,087	8261	------	------	------

NET PRESENT VALUE (NPV) ANALYSIS

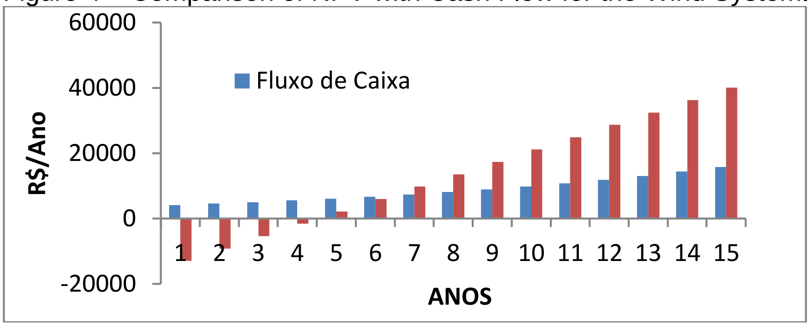
The option for the NPV criterion is justified, as the method considers the difference in the returns obtained in net cash flows, discounted from future periods in relation to the initial investment. In this way, it provides an indication of how much the project will improve the position of the capital invested by the entrepreneur or the project's income in relation to the cost of capital. As shown in Fig. 3, the photovoltaic system becomes viable from the sixth year onwards, and in the eighth year the NPV begins to exceed the cash flow steadily and progressively.

Figure 3 – Comparison of NPV with Cash Flow for the Photovoltaic system.



For the composite system with wind turbine, the NPV becomes viable from the fifth year and exceeds the cash flow disbursement in the seventh year, also in a constant and progressive way, as shown in Fig. 4. In both systems, it is verified that they are viable projects because they present positive NPV in most years.

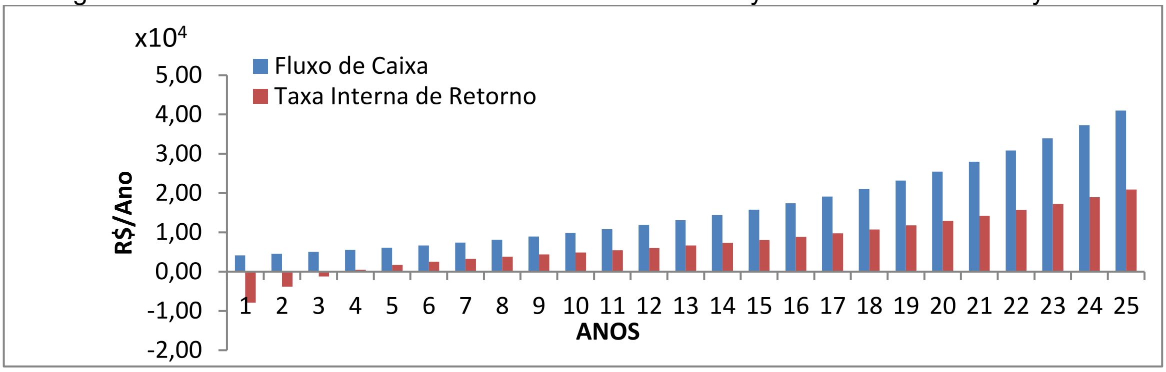
Figure 4 – Comparison of NPV with Cash Flow for the Wind System.



INTERNAL RATE OF RETURN (IRR) ANALYSIS

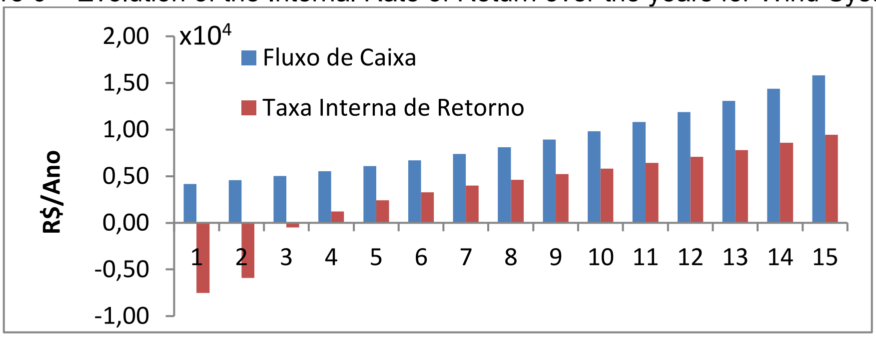
The Internal Rate of Return is when the NPV is equal to zero, so Fig. 5 shows the evolution of the IRR, showing that from the fifth year onwards the photovoltaic systems start to have a positive IRR, therefore viable, and that between the fourth and fifth year the IRR exceeds the Minimum Attractiveness Rate (ART = 6.28% p.a.).

Figure 5 – Evolution of the Internal Rate of Return over the years for Photovoltaic Systems



For the wind system, the viability is verified in the fourth year, as well as from the fourth the IRR exceeds the Minimum Attractiveness Rate. It can be seen that in both systems the IRR exceeds the MAT in the same period over time.

Figure 6 – Evolution of the Internal Rate of Return over the years for Wind Systems



ANALYSIS BY EQUIVALENT UNIFORM ANNUITY (AE)

The Equivalent Annuity method is an indicator of how the economic income generated in a project would be distributed and if such distribution would be equitable for each year, which is equivalent to distributing the NPV over the useful life of the project, transforming it into an equivalent uniform series, which can be compared between projects of different duration. Thus, it is enough to make use of Eq. 3 for photovoltaic systems with a duration of 25 years and for wind systems with a duration of 15 years, for investments of R$ 19,653.20 and R$ 16,734.00 respectively, with an energy inflation rate of 10%, remembering that the NPV of each system is calculated by Eq. 1, Logo:

$$AE_{Fotovoltaico} = \frac{VPL_{Fotovoltaico}}{a_{n,k\%}} = \frac{VPL_{Fotovoltaico}}{\left[\frac{(1+k)^n - 1}{(1+k)^n \times k}\right]} = \frac{74.982}{\left[\frac{(1+0,1)^{25} - 1}{(1+0,1)^{25} \times 0,1}\right]} = 8.261 R\$ / Ano$$

$$AE_{Aerogerador} = \frac{VPL_{Aerogerador}}{a_{n,k\%}} = \frac{VPL_{Aerogerador}}{\left[\frac{(1+k)^n - 1}{(1+k)^n \times k}\right]} = \frac{40.048}{\left[\frac{(1+0,1)^{15} - 1}{(1+0,1)^{15} \times 0,1}\right]} = 5.265 R\$ / Ano$$

As AEFotvoltaic is higher than AEAerogenerator, the first alternative is preferable, as the photovoltaic system creates more value per unit of time.

ANNUAL EQUIVALENT COST (CAE) ANALYSIS

The Equivalent Annual Cost being a prorated per unit of time of the investment costs, so applies Eq. 4 for the due costs and the annualized costs for the said systems under study are obtained, therefore:

$$CAE_{Fotovoltaico} = \frac{I_{Fotovoltaico}}{a_{n,k\%}} = \frac{I_{Fotovoltaico}}{\left[\frac{(1+k)^n - 1}{(1+k)^n \times k}\right]} = \frac{19.653,20}{\left[\frac{(1+0,1)^{25} - 1}{(1+0,1)^{25} \times 0,1}\right]} = 2.165,00 R\$ / \mathrm{A}\, no$$

$$CAE_{Aerogerador} = \frac{I_{Aerogerador}}{a_{n,k\%}} = \frac{I_{Aerorador}}{\left[\frac{(1+k)^n - 1}{(1+k)^n \times k}\right]} = \frac{16.734,00}{\left[\frac{(1+0,1)^{15} - 1}{(1+0,1)^{15} \times 0,1}\right]} = 2.200,00 R\$ / \mathrm{A}\, no$$

The equivalent annual cost of the photovoltaic system is lower, even though it requires a higher investment, as this investment will be economically prorated over a longer period.

PAYBACK ANALYSIS

As this indicator is used in conjunction with NPV and IRR, Eq is used. 5, Since time T is an integer and positive value and it is easier to take the year corresponds to the investment and compare it with the initial amount invested. For the photovoltaic system, the investment was R$ 19,653.20 and for the fifth and sixth year, the following result was obtained:

$$I = \sum_{t=1}^{T} \frac{FC_t}{(1+i^*)^t} = \frac{FC_1}{(1+k)^1} + \frac{FC_2}{(1+k)^2} + \frac{FC_3}{(1+k)^3} + \frac{FC_4}{(1+k)^4} + \frac{FC_5}{(1+k)^5} = R\$18.927,00$$

$$I = \sum_{t=1}^{T} \frac{FC_t}{(1+i^*)^t} = \frac{FC_1}{(1+k)^1} + \frac{FC_2}{(1+k)^2} + \frac{FC_3}{(1+k)^3} + \frac{FC_4}{(1+k)^4} + \frac{FC_5}{(1+k)^5} + \frac{FC_6}{(1+k)^6} = R\$22.713,00$$

Therefore, the payback of this will be reached between the 5th and 6th year.

For the wind system, the investment was R$ 16,734.00 and the analysis for the fourth and fifth years was carried out with the following results:

$$I = \sum_{t=1}^{T} \frac{FC_t}{(1+i^*)^t} = \frac{FC_1}{(1+k)^1} + \frac{FC_2}{(1+k)^2} + \frac{FC_3}{(1+k)^3} + \frac{FC_4}{(1+k)^4} = R\$15.142,00$$

$$I = \sum_{t=1}^{T} \frac{FC_t}{(1+i^*)^t} = \frac{FC_1}{(1+k)^1} + \frac{FC_2}{(1+k)^2} + \frac{FC_3}{(1+k)^3} + \frac{FC_4}{(1+k)^4} + \frac{FC_5}{(1+k)^5} = R\$18.927,00$$

So the payback of the system with wind turbines would be reached between the fourth and fifth year.

CONCLUSIONS

From the analysis of the data obtained with the simulation of two projects with a peak power of 2 kW, it was possible to determine the indices of economic criteria to establish which distributed microgeneration system of electricity is more viable. By the criterion of Net Present Value (NPV), the photovoltaic system presented better performance throughout its useful life, showing that from the sixth year the system becomes viable, with nineteen years of accumulation of monetary valuation. It is worth mentioning that the study was carried out during the warranty time of the system, and can add to this period at least five more, which makes thirty years of use on average. The wind turbine system, on the other hand, would have only eleven years of value accumulation due to its useful life being much shorter. By the criterion of the Internal Rate of Return (IRR) in both systems this rate cancels the NPV between the third and fourth year, but for the wind system on that date the IRR (12.28%) exceeds the cost of capital (10%), while in the photovoltaic system this only happens in the fifth year (16.67%) and on that date the system with wind turbine already accumulates 24%.

By the criterion of the Equivalent Uniform Annuity (EUA), the photovoltaic system proved to be a more viable alternative because it generates more value over time. The same happens when using the Equivalent Annual Cost (CAE) criterion, in which the photovoltaic system proved to be less, pointing to it as a more viable alternative.

And finally, by the discounted Payback method, there is a proximity of only one year, since the photovoltaic system recovers the capital invested between the fifth and sixth year and the wind between the fourth and fifth year, attributed to the photovoltaic system greater appreciation time with the corresponding cash flows. Therefore, by the criteria analyzed, it is verified that the photovoltaic system for low power is more viable.

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