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COMMERCIAL AND RESIDENTIAL TECHNO-ECONOMIC ANALYSIS OF A GRID-CONNECTED PV SYSTEM – RIO DE JANEIRO’S CASE STUDY

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Abstract. Sustainable development and renewable energy sources are topics that have impacted the global scenario and are contributing to a greater awareness of the need to preserve the planet's natural resources and still being able to supply the energy demand. Government play a major role creating incentives and policies that provide the proper scenario to new renewable technologies rise. This paper presents a technological and financial analysis of a PV grid-connected system at residential and commercial scale located at Rio de Janeiro's State. The model is evaluated considering technical aspects like safety, compatibility, energy production optimization and the economic tools payback and net present value. Both scenarios indicates viability with paybacks lesser than 7 years for a 25 years system. At the end of the 2.7 kWp residential and 11.7 kWp commercial PV system life cycle it is expected a mean energy production of 315 kWh/month and 1316 kWh/month leading to a cumulative electricity billing saving of almost R\$100,000.00 and R\$ 450,000.00, respectively. Since the net metering mechanism implementation in Brazil there is great expectations in the country's photovoltaic market growth because of its great solar resource and PV's potential for distributed generation.

Keywords: Sustainability, renewable energy, photovoltaic, financial viability, Rio de Janeiro

1. INTRODUCTION

Sustainable development and renewable energy sources are topics that have impacted the global scenario due to last decades events related to climate change and Earth's resources shortage, as a consequence governments have been creating incentives and/or regulations in order to increase the shares of clean energy sources and develop new forms of cleaner technologies.

Accordingly with the Brazilian Electricity Regulatory Agency (ANEEL) about 60% of Brazil's energy mix comes from hydroelectric power plants, such dependency represents a risk to the economy due to its seasonality, i.e., hydropower shortage from drought phenomenon raises electricity surcharge and requires fossil fuel power plants to be used, adding tons of CO₂ at the planet's atmosphere. In 2016 Brazil signed the Paris Agreement and efforts are being made in order to increase its energy mix share of renewables, after the creation of a net metering system through a new regulation for distributed energy a rapid increase in PV system installations are being reported.

By the end of 2017 Brazil reached the milestone of 1 GW of electric energy converted from its abundant sunlight, a small share of 0.8% of the total energy production, but recent reports shows that Brazil is expected to grow more rapidly its PV capacity due mainly to its first tenders and utility-scale constructions being completed and the continuous decrease in component's costs. (EXAME, 2018)

Several studies were carried out since the implementation of the net metering mechanism, (Holderman et al, 2014; Campo et al, 2014; De Almeida et al, 2017) and most of Brazil's territory, especially the northeast, showed economic feasibility. Most studies based the PV system cost in European market and simulates a currency conversion (ABINEE, 2012), but after 6 years of an expanding market it is possible to rely on local prices, (AHK, 2017) and (GREENER, 2018) shows that residential and commercial photovoltaic prices are reducing about 24% every year.

This study aims to analyze the viability under the technical and financial perspective of a PV grid connected system at residential and commercial scale using data from recent studies regarding the photovoltaic market and solar resource at Rio de Janeiro.

2. PV FUNDAMENTALS

2.1 Solar resource

The energy provided by the sun can be used in many ways, for example, passively in buildings (temperature and light control) or harvesting it through a technology like concentrating solar power or photovoltaic. The photovoltaic effect, occurs when light (photons) collides a PV cell and provide enough energy to free some electrons producing a voltage due to the semiconductor's aspect. Because of the photon's high energy potential understanding and measuring it is essential to design a suitable PV system. The solar irradiation is the amount of energy per area in a certain period of time, usually years and can be used to determine the feasibility of a PV project. Countries located between the tropics are most likely to have a higher solar irradiance, therefore, PV technology should play an important role in those countries. The top producers have similar or lower solar irradiation if compared to Brazil's.

According to a recent study carried out in Rio de Janeiro's State by (PUC University and EGP Energia, 2016) Rio's mean annual global horizontal irradiation (GHI) is about 5 kW/m²/day or 1825 kW/m²/year, although it is a value below the country's best location (northeast semi-arid) it is similar to top PV energy producers like U.S, Germany and China.

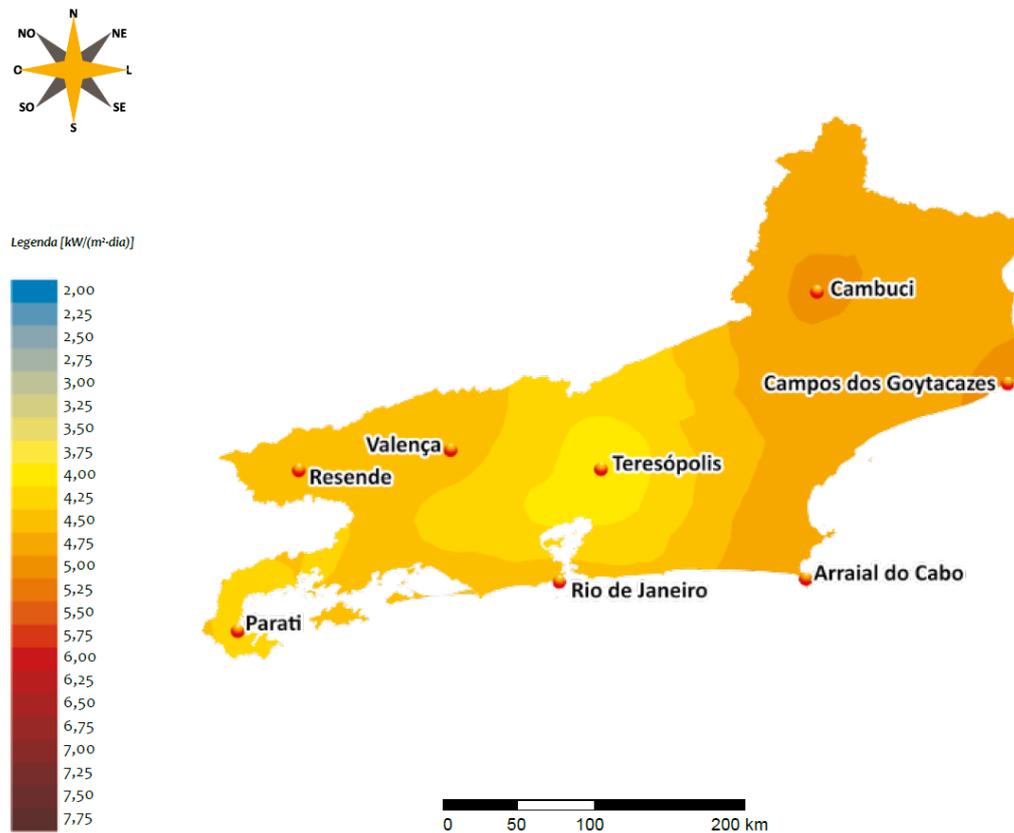


Figure 1. Rio de Janeiro's annual global irradiation map. (Atlas Rio Solar, 2016)

2.2 PV Technology

Some authors divide the PV technologies in three generations, the so called first generation that constitutes modules of crystalline silicon is used by more than 90% of the world's PV installations. As a consequence the majority of present studies are related to silicon based cells, primarily, polycrystalline silicon (p-Si), this study will consider a PV system using p-Si modules due to its widespreadness.

The main components of a grid connected PV system are modules, inverter and the balance of system which includes wiring, protection devices, connectors, array mount and other minor components that can change depending on the local regulation but also necessary to a proper installation.

In order to avoid clipping losses the DC/AC ratio must be taken into account as the compatibility combination to ensure that the short circuit current and tension is not exceeding or below inverter range (Messenger, 2017) so the following arrangement were made:

Table 1. Technical considerations adopted.

	Residential	Commercial
Module	CS6K-270P	CS6X-325P
DC output	2700 W	11700 W
Series x Parallel modules	10x1	9x4
Inverter	SB 2500	SB 10000TL-US
AC output	2500 W	10100 kW
DC/AC ratio	1.08	1.17

3. ENERGY MARKET AND ECONOMIC ASPECTS

3.1 Energy Market

In 2012 the Brazilian Regulatory Agency for Electricity (ANEEL) consolidated a regulatory mark which allowed consumers exchange their energy produced for energy credits and implemented rules and regulations that compensates the consumer by the power feed back into the grid. Several countries started their policies regarding distributed generation with a net metering system such as the REN 482/2012 implemented in Brazil.

After 6 years since Brazil's first regulation on distributed generation, it is remarkable the country's new systems numbers. Accordingly with ANEEL more than 10000 installations occurred in that period and Solar PV is responsible for about 99% of the total renewable energy systems, such participation can be explained by the substantial price drops of modules and other components of the system, the region abundant solar resource, the ongoing growth of electricity retail price due to its dependence on hydropower and the population's environmental awareness.

Since the rapid PV capacity growth, studies are being carried out with local retailers and customers in order to track down the price over the years and the impact that a new regulation have on the market. Accordingly with (AHK, 2017) and (GREENER, 2018) depending on the system size the average residential price is R\$ 7.69/Wp and R\$ 6.37/Wp for a commercial PV grid connected system.

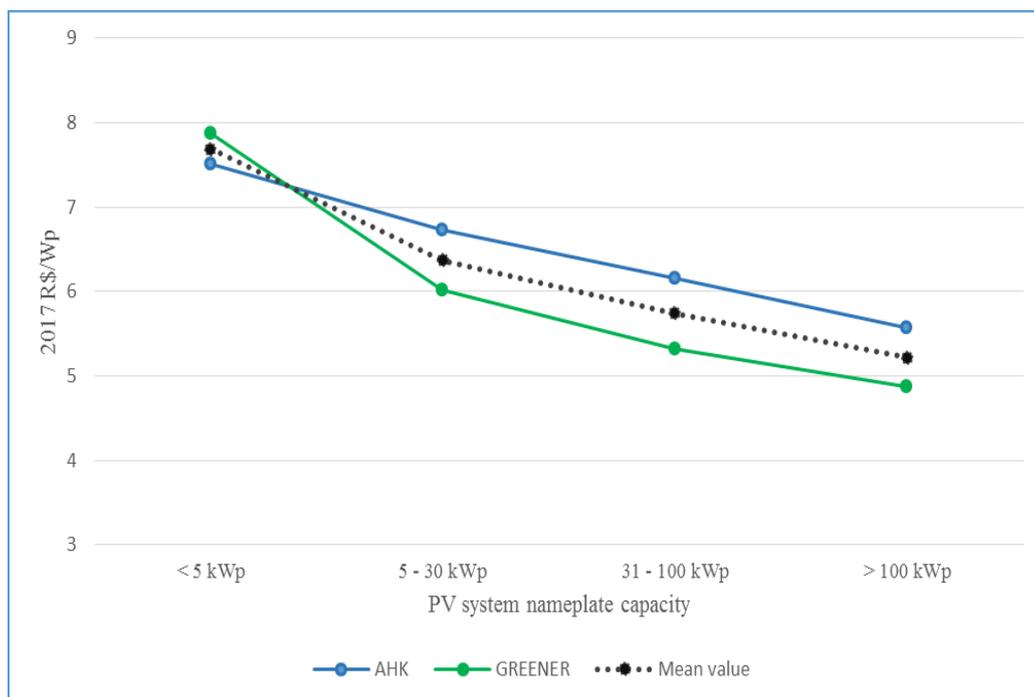


Figure 2. National prices reported by local retailers in a market research.

Another important aspect that must be considered is the local electricity retail price, in fact, Rio de Janeiro is one of the most expensive states when it comes to electricity usage. For this model it will be assumed the value of R\$ 0.77/kWh¹ or \$ 0.21/kWh, as a comparison, California's residential rate is around \$ 0.15/kWh.

3.2 Investment Analysis

¹ 3.74 BRL/USD. Accessed May, 18 2018

The economic feasibility is calculated based on the initial investment, the annual operation and maintenance cost and the inverter replacement at the 10th year constituting the costs involved. In relation to the direct benefits, it will be calculated the stream of annual earnings, i.e. the amount of money saved because of the PV system.

The investment analysis tools selected to determine the economic viability are the most common and useful used by CFO's for small/medium size projects, discounted payback and net present value (Gitman, 2004). The discounted payback is the amount of time required for the investor recover its initial invested value considering the value of money over the time, in this study, using the Brazilian inflation rate IPCA. The net present value is found by subtracting the total costs ($Costs_{pv}$) which is the initial investment and operational costs from the present value of its cash inflows (CI_{pv}) discounted at a specific rate (r), in this case, the SELIC discount rate.

$$NPV = \sum_1^t \frac{CI_{pv}}{(1+r)^t} - Costs_{pv} \quad (1)$$

4. METHODOLOGY

The method to determine the annual energy generation (E_a) is recommended by the International Energy Agency through the guidelines at IEC 61724, where it is necessary the nameplate system capacity (P_{pv}), the local GHI over the standard test condition ($G = 1000 \text{ W/m}^2$) and the performance ratio (PR) of the system, a value assumed to be 75%.

$$E_a = \frac{P_{pv} \times PR \times H_{local}}{G} \times 365 \quad (2)$$

Another relevant aspect to be considered in this calculation is the module efficiency derate (f_{derate}), usually assumed to be -0.5% per year, leading to:

$$E_{total} = \int_1^t E_a \times (1 - f_{derate})^t \quad (3)$$

Finally, considering the electricity retail price (R) and its increase over the years (r), in Brazil's case it increases around 9%/year, discounted by the inflation (i) the cash inflow (CI_{pv}) can be obtained, mathematically:

$$CI_{pv} = \int_1^t \frac{E_a \times (1 - f_{derate})^t \times R \times (1+r)^t}{(1+i)^t} dt \quad (4)$$

5. RESULTS

5.1 Residential Results

A 2.7 kWp PV residential system was modelled in Rio de Janeiro, occupying an area of 16.5 m² at an initial cost of R\$ 20,763.00 (\$ 5,551.60). The system is expected to produce around 315 kWh/month and should save almost R\$ 3,000.00 in electricity bills at the first year and R\$ 8,000.00 at the end of its life cycle.

The following parameters were considered in this model:

Table 2. Assumed parameters used for the residential scenario.

Symbol	Description	Value	Unit
P_o	System nameplate capacity	2700	Wp
H_{local}	Local GHI	1825	kW/m ² /year
PR	Performance Ratio	75	%
f_{derate}	Efficiency derate factor	-0.5	%/year
R	Electricity retail price	0.77	R\$/kWh
r	Annual electricity rate increase	9	%/year
i	Inflation (IPCA)	4	%/year
C_{wp}	Watt-peak Cost	7.69	R\$/Wp
t	Life cycle	25	Years

The payback time of the residential system is 6.71 years and at the end of its life cycle a total of almost R\$ 100,000.00 was saved with electricity bills.

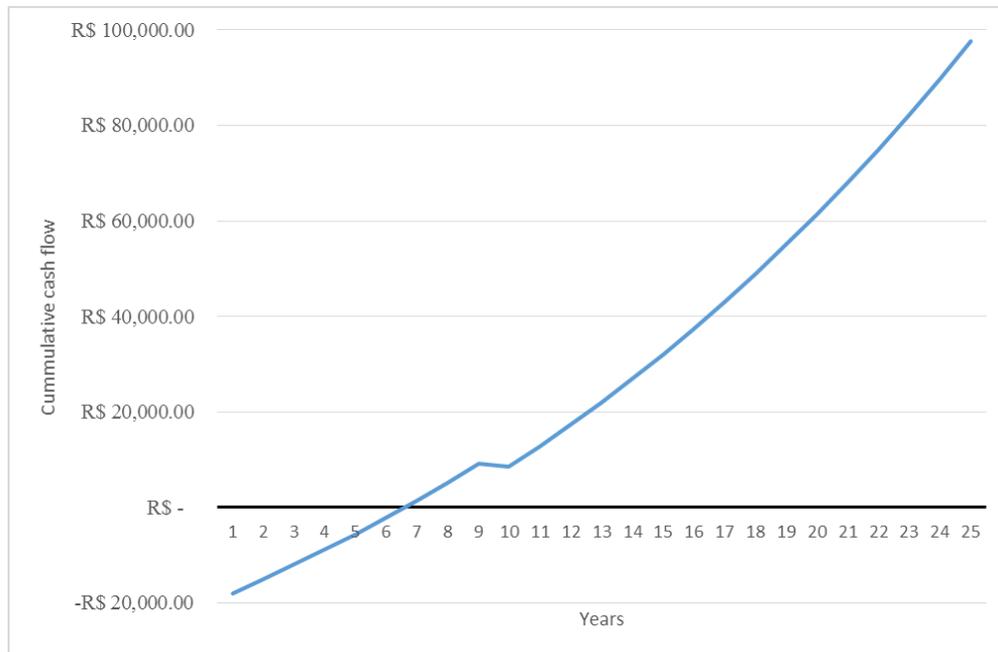


Figure 3. Residential system payback time.

Analyzing the net present value, the investment is considered viable if $NPV > 0$, as a consequence, the discount rate should be less than when the $NPV = 0$. Since it is a challenge to predict a discount rate for the next 25 years, for this model was used a range varying from 9 – 26%. Historically, Brazil's mean SELIC rate over the last couple decades is around 12%, accordingly with Fig. 4 the internal rate of return (IRR) is financially acceptable when $SELIC < 17.9\%$, which make the investment profitable even in worst scenarios.

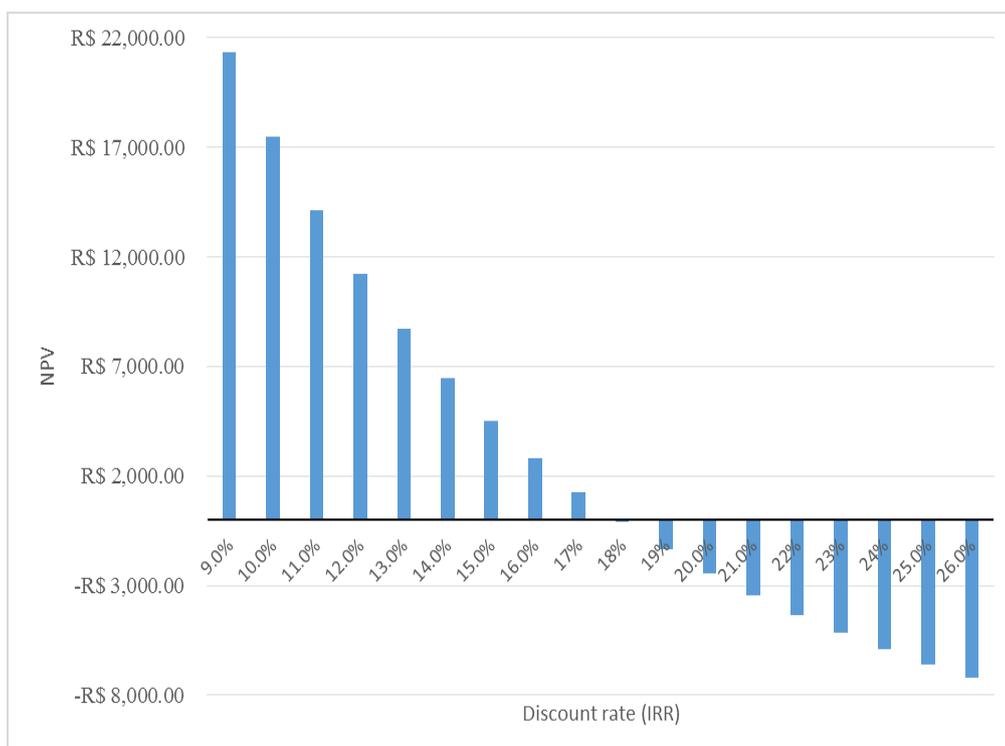


Figure 4. Net present value for a varying discount rate at residential scale.

5.2 Commercial Results

A fully-operational 11.7 kWp PV commercial system it is supposed to cost R\$ 74,529.00 and would need a total of 51.3 m² area with a total of 36 modules arranged in 4 strings of 9 series connected modules. The commercial system should deliver 1316 kWh/month which would lead to a saving of nearly R\$ 13,000.00 for the first year and about R\$ 35,000.00 at the 25th year.

Table 3. Assumed parameters used for the commercial scenario.

Symbol	Description	Value	Unit
P_o	System nameplate capacity	11700	Wp
H_{local}	Local GHI	1825	kW/m ² /year
PR	Performance Ratio	75	%
f_{derate}	Efficiency derate factor	-0.5	%/year
R	Electricity retail price	0.77	R\$/kWh
r	Annual electricity rate increase	9	%/year
i	Inflation (IPCA)	4	%/year
C_{wp}	Watt-peak Cost	6.37	R\$/Wp
t	Life cycle	25	years

The payback time occurs at 5.56 years and the total savings at the end of the system’s life cycle is R\$ 446,162.00, which is represented at the figure below.

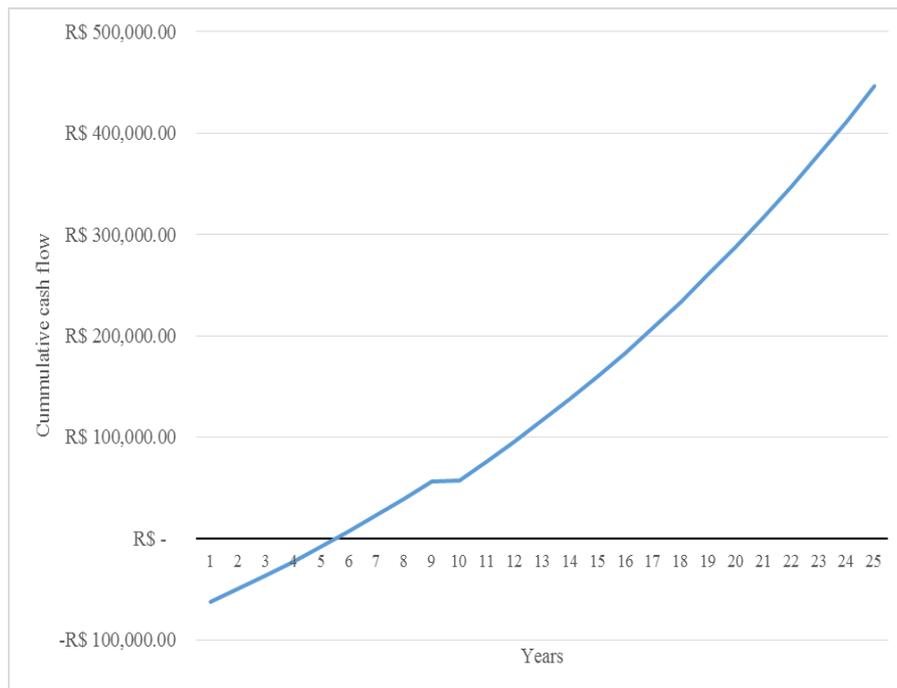


Figure 5. Commercial system payback time.

Since its lower price per Watt-peak the commercial scenario for the grid connected PV system should be more likely to have a positive NPV. Accordingly with Fig. 6, the only scenario this investment is not viable it is when $IRR > 21\%$ which is a considerably high value for a discount rate, therefore the project should be accepted.

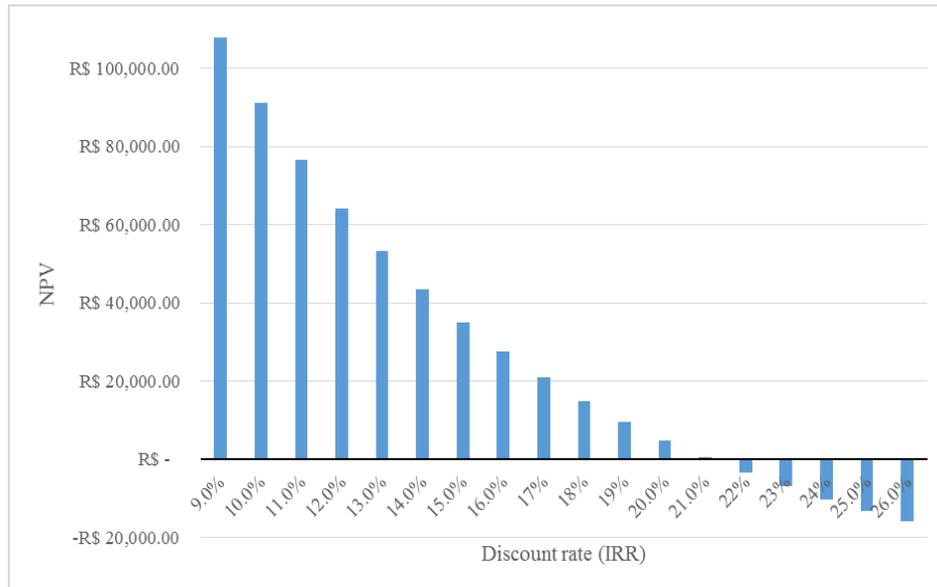


Figure 6. Net present value for a varying discount rate at commercial scale.

6. CONCLUSION

This study examines the economic viability and the technical potential of a 2.7 kWp and 11.7 kWp PV grid connected system at residential and commercial scale, respectively, installed in Rio de Janeiro's region. Rio's selection was due to its good solar resource and high electricity pricing, other parameters considered in this study are safety, compatibility, performance, market supply and electricity load curve.

Both scenarios, residential and commercial, indicates an economically viable project. The payback time results must be evaluated individually, i.e., some investors could considered it viable and others could not. The amortization occurs at 6.71 years at residential scale and 5.56 years at commercial scale for a system expected to last 25 years, both cases have almost a zero cash inflow at the 10th year due to the inverter replacement, so the PV system profits would pay for itself. The net present value analysis obtained in both scenarios are positive for the majority of the possible discount rates, therefore, the project should provide profits over its life time.

The Brazilian photovoltaic market is not fully developed yet and studies should be continued since the PV costs are decreasing every year and historically the electricity price increases above the inflation. Further studies regarding distributed generation policies should be taken in order to implement an effective transition from net metering system to a feed in tariff system, therefore leading to more acceptability among the population.

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