18th Brazilian Congress of Thermal Sciences and Engineering
November 16-20, 2020 (Online)

ENC-2020-0722
ANALYSIS OF THE TECHNO-ECONOMIC PERFORMANCE FOR A SOLAR PHOTOVOLTAIC SYSTEM BY NET PRESENT VALUE AND PAYBACK PERIOD OVER A TWENTY-FIVE YEAR LIFE-CYCLE

João Pedro Duveen Cunha
Priscila de Jesus Freitas Pinto
Marcos Filardy Curi
Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, Rio de Janeiro, Rodovia Mário Covas, lote J2, quadra J, Itaguaí, 23812-101, Brazil
pedroduveen@gmail.com; priscila.pinto@cefet-rj.br; marcos.curi@cefet-rj.br

Abstract. *In the last years, great concerns about climate change and Earth's resources shortage are being created with continuous population growth and CO² emissions. In that sense, renewables energies sources have increased the planet attention for R&D. Governments have been creating incentives and/or regulations in order to increase the shares of clean energy and develop new forms of cleaner technologies. This work studied the viability, by technological and economic analysis, of a photovoltaic generation system in a commercial company and a residential case at Rio de Janeiro. To analyzes the profitability of the project, the economic analysis is carried out by the Net Present Value and Payback period. Both scenarios indicate viability with paybacks lesser than 7 years for a system that is supposed to last 25 years. It is expected mean energy production of 315 kWh/month and 1316 kWh/month for the 2.7 kWp residential and 11.7 kWp commercial PV system, respectively. Leading to a cumulative electricity billing saving of almost R$43,000.00 (residential) and R$ 200,000.00 (commercial) over its lifetime. Since the net metering mechanism implementation in Brazil, there are great expectations in the country's photovoltaic market growth because of its great solar resource.*

Keywords: *Sustainability, renewable energy, photovoltaic, financial viability*

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 government have been creating incentives and/or regulations in order to increase the shares of clean energy sources and develop new forms of cleaner technologies.

By the Brazilian Electricity Regulatory Agency (ANEEL) about 63% 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 CO_2 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 sources, 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.

At 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. However, recent reports show 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 the European market and simulated a currency conversion (ABINEE, 2012). After 8 years of an expanding market, it is possible to rely on local prices, (AHK, 2019) and (GREENER, 2019) releases a market report every year showing costs for system and installation so customers can compare and better understand their investment. Since the PV system presents features of easy installation and reliability, as well as the possibility to produce electricity and heat and function in combination with other energy sources (Nižeti´c et al., 2017), financial evaluation is necessary to indicate its best applications (Zeraatpisheh , 2018, Li et al., 2018).

This paper performs the long-term technical and economic analysis in an uncertain environment of a system connected to the PV network in a residential and commercial scale, using data from recent studies on the photovoltaic market and the solar resource in Rio de Janeiro State. The results achieved shows excellent performance for application in long-term projects. Due to high volatility in solar energy investments, especially in countries like Brazil, where economic cycles are recurrent, the approach presented here mitigate the investment risks, in that way, contributing to the local literature.

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 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, 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, because of that, 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/m^2/day or 1825 kW/m^2/year. However, it is a value below the country`s best location (northeast semi-arid) this is similar to top PV energy producers like the U.S., Germany and China.

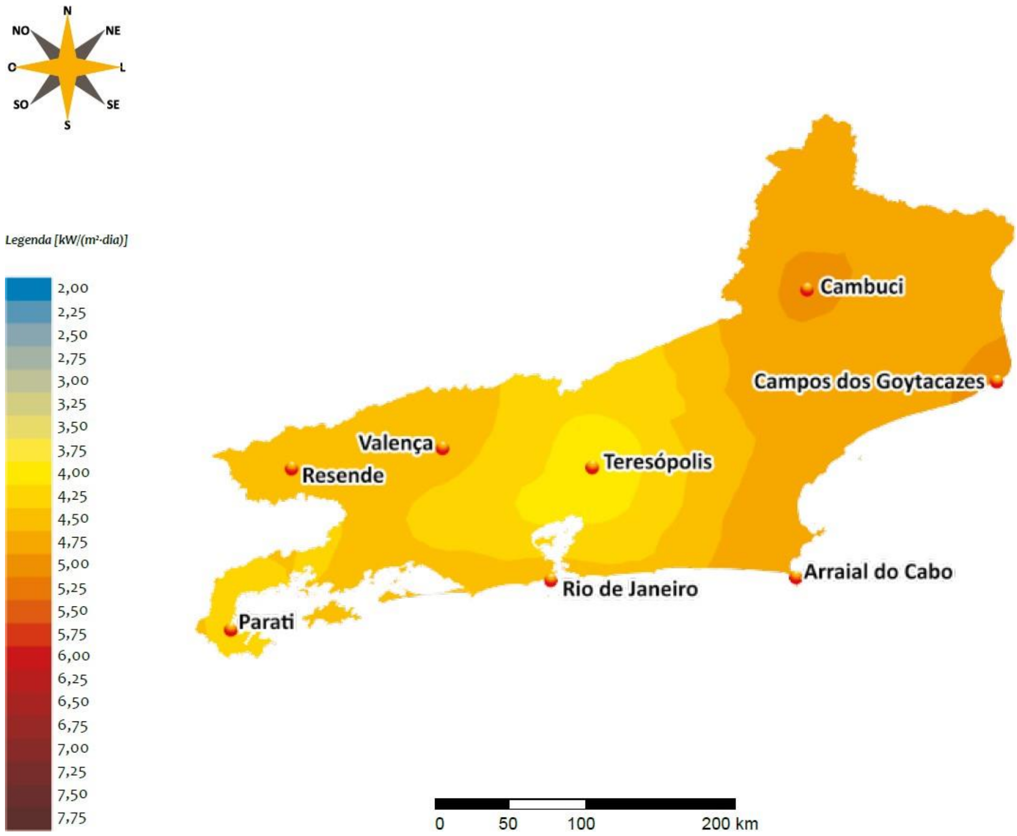

Figure 1. Rio de Janeiro's annual global irradiation map. (Atlas Rio Solar, 2016)

2.2 Photovoltaic technology

Some authors divide the PV technologies into 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. Consequently, 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 low cost.

The main components of a grid-connected PV system are modules, inverter and the balance of the 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 was 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 ECONOMICS 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 feedback 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 8 years since Brazil's first regulation on distributed generation, it is remarkable the country's new systems numbers. According to ANEEL, there are more than 250,000 PV systems installed across Brazil, and they are responsible for about 95% of the total renewable energy systems for distributed energy. The modular installation advantage can explain such participation over other sources, substantial price drops of system's components, 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 to track down the price over the years and the impact that a new regulation has on the market. According to (GREENER, 2019) depending on the system size the average residential price is R$ 6.04/Wp and R$ 4.23/Wp for a commercial PV grid-connected system. Another important aspect that must be considered is the local electricity retail price, Rio de Janeiro is one of the most expensive states when it comes to electricity usage. For this work, the value of R$ 0.77/kWh was used.

3.2 Investment analysis

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. Concerning 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 to recover its initial investment value considering the value of money over 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.

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

4. METHODOLOGY

To determine the annual energy generation (E_a), the International Energy Agency recommended the guidelines at IEC 61724. Where it is necessary the nameplate system capacity (P_{pv}), the local GHI, H_{local}, over the standard test condition (G= 1000 W/m²) and the performance ratio (PR) of the system, a value assumed to be 75%.

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

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:

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

Where *t* is the life cycle, 25 years is the life cycle considered, as mentioned. 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*), in this study set to 4%/year, the cash inflow (CI_{pv}) can be obtained, mathematically:

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

5. RESULTS

A 2.7 kWp PV residential system was modelled in Rio de Janeiro, occupying an area of 16.5 m^2 at an initial cost of R$ 16,308.00 and H_{local}=1825 kW/m^2/year. The system is expected to produce around 315 kWh/month and should save almost R$ 3,000.00 in electricity bills in the first year and R$ 8,000.00 at the end of its life cycle.

For a watt-peak cost, C_{Wp} set as R$6,04/Wp, the payback time of the residential system obtained was 6 years and at the end of its life cycle, a total of about R$ 43,000.00 was saved with electricity bills.

Analyzing the net present value, the investment is considered viable if NPV>0, therefore, 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, 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. 2 the internal rate of return (IRR) is financially acceptable when SELIC<17.9%, which make the investment profitable even in worst scenarios.

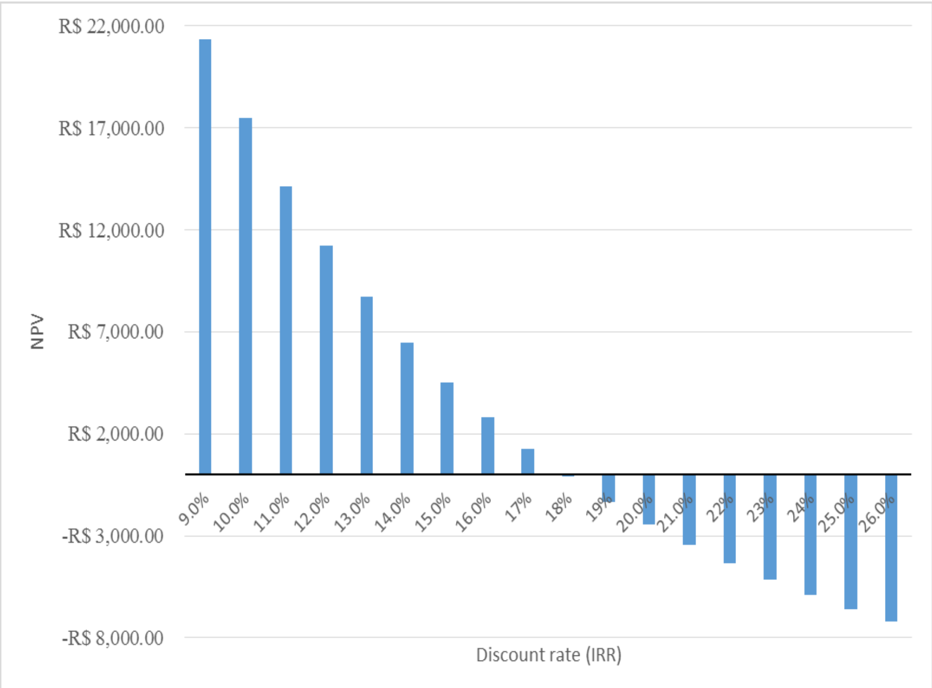

Figure 2. Net present value for a varying discount rate at residential scale

For commercial application, a fully-operational 11.7 kWp PV system is supposed to cost R$ 49,491.00 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 and

H_{local}=1825 kW/m^2/year. 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 in the 25th year.

For a watt-peak cost, CWp set as R$4,23/Wp, the payback time, Fig. 3, occurs in 5 years and the total savings with electricity bills at the end of the system's life cycle is almost R$ 200,000.00.

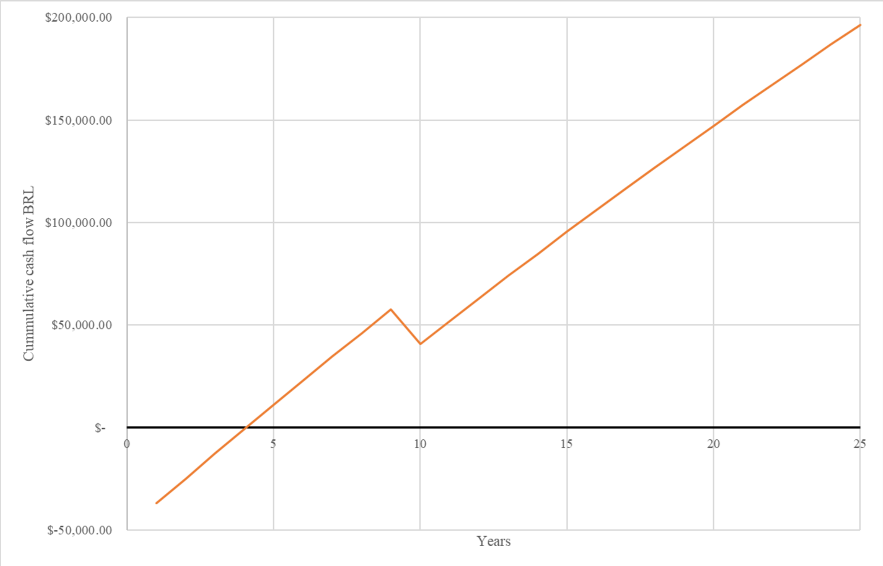

Figure 3. Commercial system payback time

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. 4, 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.

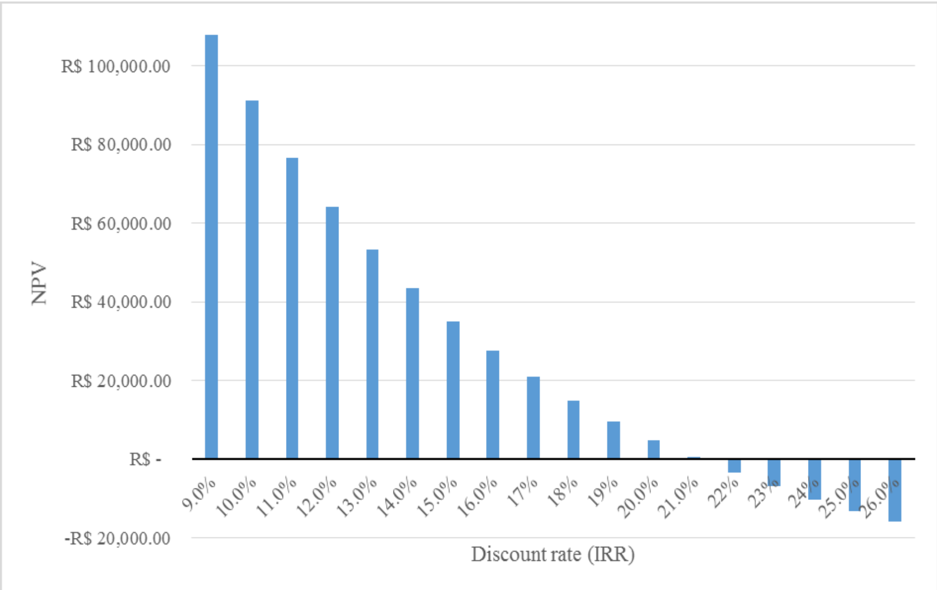

Figure 4. Net present value for a varying discount rate at commercial scale

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 consider it viable and others could not. The amortization occurs in 6 years at residential scale and 5 years for a commercial scale for a system expected to last 25 years, both cases would have negative cash inflow at the 10th year due to the inverter replacement, but considering the cumulative earnings the PV system would pay for it. 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 lifetime.

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 to implement an effective transition from net metering system to a feed in tariff system, therefore leading to more acceptability among the population.

7. REFERENCES

ABINEE, 2012. "*Propostas para Inserção da Energia Solar Fotovoltaica na Matriz Brasileira*", ABINEE, Brasília.

ANEEL, Resolução Normativa nº. 687/2015 de 24 de Novembro de 2015. Diário Oficial da União, Brasília, DF, 2015.

ANEEL, *Capacidade Brasil.* <http://www2.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm>.

AHK, IDEAL Institute, *The Brazilian Market Of Distributed Solar PV Generation - Annual Report 2017*, 2017

Campos, H. M., Manrique, A. K. R., Kobiski, B. V., et al., 2014 "*Study of technical feasibility and the payback period of the invested capital for the installation of a grid-connected photovoltaic system at the library of the Technological Federal University of Paraná*". In "International Journal of Energy and Environment

De Almeida, Renata Ribeiro Guedes et al, 2017. "*Proposição de uma metodologia para análise de viabilidade econômica de uma usina fotovoltaica".* In "Cobenge 2016, revista principia"

EXAME, 2018. "*Brasil pode mais que dobrar capacidade em usinas solares em 2018*", accessed: 16 Feb. 2018 < https://exame.abril.com.br/economia/brasil-pode-mais-que-dobrar-capacidade-em-usinas-solares-em-2018>

Gitman, L. J. (2004). "*Principles of managerial finance*" (10th ed.). Delhi: Pearson Education Ltd. 10th edition

GREENER, 2018. "*Estudo Estratégico Mercado Fotovoltaico de Geração Distribuída"*

Holdermann C, Kissel J, Beigel J., 2014. "*Distributed photovoltaic generation in Brazil: an economic viability analysis of small-scale photovoltaic systems in the residential and commercial sectors*". Energy Policy 2014;67:612–7.

IEC, "*Photovoltaic system performance monitoring guidelines for measurement, data exchange and analysis*", 1998. IEC Standard 61724, Geneva, Switzerland

Li, Y.; Wu, M.; Li, Z. A Real Options Analysis for Renewable Energy Investment Decisions under China Carbon Trading Market. Energies 2018, 11, 1817. doi:10.3390/en11071817.

Messenger, R., Abtahi, A., 2017. "*Photovoltaic Systems Engineering*", Taylor & Francis Group PUC, EGP Energia, 2016. "*Atlas Rio Solar*", Ed PUC-Rio

Nižeti´c, S.; et al. Hybrid energy scenarios for residential applications based on the heat pump split air-conditioning units for operation in the Mediterranean climate conditions. Energy Build. 2017, 140, 110–120. doi:10.1016/j.enbuild.2017.01.064.

Zeraatpisheh, M.; Arababadi, R.; Saffari Pour, M. Economic Analysis for Residential Solar PV Systems Based on Different Demand Charge Tariffs. Energies 2018, 11, 3271. doi: 10.3390/en11123271.

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.