

Computer Tool for Sizing and Economic Assessment of Grid-Connected Photovoltaic System

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Abstract

Thanks to the location close to the Equator line, Colombia offers an advantage location for solar applications. This is the case of Neiva, a city located in the south of Colombia where the average temperature and irradiance are 31 °C and 4 kW/m² respectively. This paper describes the development of an investment payback solar calculator (PSC) software for residential and commercial PV solar applications in Neiva. The PSC uses both the average solar energy and the electricity prices to estimate the rate of return on investment, the payback period (PBP), the net present value (NPV) as well as the environmental impact. The PCS software is then evaluated using a historical and statistical information from NASA, adjusted with the results of a small scale 1 kW grid connected PV system production. The results show that the PCS software can satisfactorily indicate the PV system size and perform an economic evaluation of the system to be implemented. The results obtained using the application developed were compared to two commercially available software Sunny Design and HOMER. The NPV and the PBP values showed that the proposed application results are like those delivered by the commercial software. Furthermore, the economic evaluation given by the developed tool uses additional information which makes it more accurate in countries where socioeconomic stratum is presented.

Keywords: PV, energy cost modelling, Renewable energy

1. Introduction

According to World Bank data, 80% of the energy consumed around the world comes from traditional energy resources like oil, coal and gas (Portafolio, 2016). This scenario causes negative impacts that governments need to address. The principal issue is the negative environmental impact to the planet that produces an increment on the global temperature caused by higher concentration of carbon dioxide in the atmosphere. Therefore, several projects are being implemented to generate power from renewable resources like solar energy.

Several contributing countries of air pollution have been developing policies and agreement related to CO₂ emission reduction and promoting carbon capture. In that way, initiatives such as applications with no-conventional energy resources are increasing in last years with the aim of reducing greenhouse gases. Countries around the world are creating new policies to reduce conventional energy consumption (Jackson, 2011; Pickard, 2016) and satisfy Kyoto agreement (Císcar & Soria, 2002). For instance, Scotland created policies that includes climate target for CO₂ reduction (Anandarajah & McDowall, 2012), Greece introduced a renewable energy policy based on electricity consumption to integrate no conventional resources in the national energy market (Economou, 2011). On the other hand, India implemented different policies to accelerate the growth of renewable energy deployment (Mahesh & Shoba Jasmin, 2013). Other countries in South America are adding more programs such as feed in tariff (Economou, 2011; Mahesh et al., 2013; Solangi et al., 2011; Chowdhury et al., 2014; del rio gonzález et al., 2008), tax incentives (Balcombe et al., 2013; Chowdhury et al., 2014; Jackson, 2011; Jimenez, Franco, & Dyner, 2016; Radomes & Arango, 2015) and net metering system (Eid, Reneses Guillén, Frías Marín, & Hakvoort, 2014; Schelly, Louie, & Pearce, 2017; Westwood & Hopwood, 2010; Wiedman & Beach, 2013) to pursuit the diffusion of renewable technology.

Nowadays, solar energy represents the second most widely used non-conventional renewable source around the world, with a production between 0.85% and 1% of the world's electricity demand (UPME & BID, 2015). Although Colombia's location offers advantages for solar applications, 78% of the primary energy resources comes from fossil fuel (Murcia et al., 2015).

The generation capacity of Colombia national interconnected system is mainly hydroelectric systems with 64%, followed by thermoelectric plants with 31%, and the remaining it is shared by minor plants, such as small hydroelectric, wind power plants and PV power plants (UPME, 2009).

The Colombian electric power demand has had a steady growth in the last decade, with an average of 2.8% each year (UPME, 2015). For that reason, the country needs to accelerate the development of technologies for energy conversion from renewable resources; to supply the required demands.

Often the most difficult question to answer is whether it makes financial sense to go forward with the project. Common questions related to these projects are: What would be a suitable size? How long would it take to recover the cost of investment? What is the impact of tax incentives on the annual cash flow? In the literature, several authors have proposed software algorithms to calculate technical sizing of PV systems (Anwari, Dom, & Rashid, 2011; Chikh, Mahrane, & Bouachri, 2011; Guerrero-Rodríguez, Rey-Boué, & Reyes-Archundia, 2017; Satapathy, Dhar, & Dash, 2017; Shukla, Sudhakar, & Baredar, 2016; Skunpong & Plangklang, 2011); whereas the economic impacts have been reported in (Bilir & Yildirim, 2017; Davidson & Steinberg, 2013; Grande, Yahyaoui, & Gómez, 2018; Hoen et al., 2017). Other works utilize an optimization procedure to adjust the size of the PV installation based on the economic impact (Anandarajah & McDowall, 2012; Bianchini, Guzzini, Pellegrini, & Saccani, 2017; Shukla et al., 2016).

This study describes the development of a software tool for the sizing and economic evaluation of a grid-tied PV system in residential applications. This paper is organized as follows. In Section 2, the irradiation data, energy produced and tariff scheme for the city of Neiva are introduced, and it is followed by the description of the computer tool developed. In Section 3, the results are presented for solar Potential, PV energy generation, trend electricity price and PCS results. Then is compared with two commercially available software—SUNNY DESIGN and HOMER—and the economic impact of the same installation in two different countries is estimated. Finally, the concluding remarks are addressed in Section 5.

2. Method

In this chapter we describe the data introduced in the tool for sizing and economic evaluation of PV systems in the city of Neiva, considering the average number of hours of sunlight consulted at NASA and the one experimentally obtained at Neiva. In addition, the cost of energy by socioeconomic status in the city is considered.

2.1 Solar Irradiance Data

The solar irradiance data for the city of Neiva was obtained from the National Aeronautics and Space Administration (NASA). To improve the accuracy and to get a clear understanding of the patterns, the data used goes from 2012 to 2016. The NASA records are contrasted with ground based meteorological stations that registered solar radiation, ambient temperature, and the wind speed. The information is also compared with a PV system that registered the sun hours for 1 year in the location of interest.

2.2 Electrical PV Production Data

The energy generated by PV installations can be calculated using the PV power capacity and the standard sun hours (taken from meteorology databases (REN21, 2015)). However, this historical data might present some variations compared to recent weather station records. Moreover, to better corroborate the results, a small scale 1 kWp grid-tied PV system was installed in the city of interest.

The installed grid-tied system (Figure 1) is composed by four (4) modules 260Wp—Canadian Solar—a 1.0 kWp SMA single-phase inverter. A current sensor meter is also installed for energy measurement and it is connected to a Raspberry Pi that sends the current data to a web server (10 min sampling time).

2.3 Electricity Tariff Information

First, an evaluation of the electricity price trend during the last two years was made to obtain the return of investment for a PV system located in Neiva. In Colombia, the compensation payment for renewable energy depends on social stratification; therefore, this parameter is also considered during the statistical analyse. Every socioeconomic stratum includes taxes incentives, and these are taken in account on the simulator algorithm.

2.4 Calculation

2.4.1 Sizing and Technical Evaluation

To meet energy requirements of consumer, the grid connected solar PV system was design based on electrical average consumption for the last 2 years.

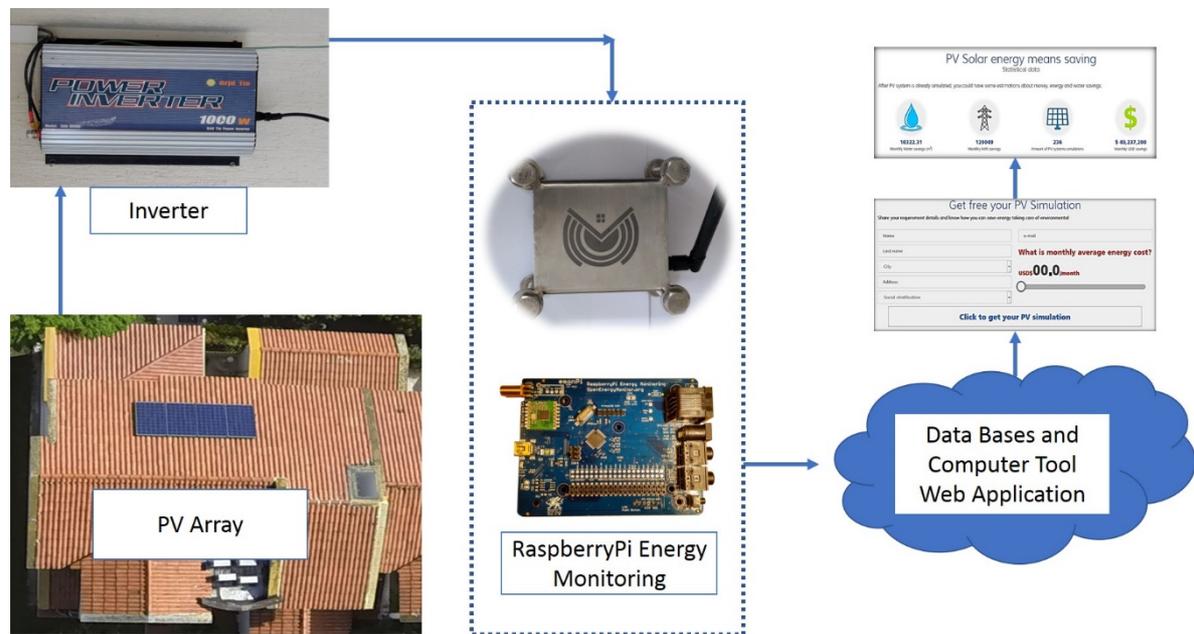


Figure 1. Grid-tied system

First, the amount of PV modules can be calculated with the average electricity consumption, solar irradiance available, and maximum power generation of the polycrystalline module. It is important to note that the PV efficiency of the PV modules used in this setup is 16.16%. The second step is to define the inverter nominal capacity based on the PV array.

Most of the residential facilities have a similar daily demand profile, the solar power demand could be the 25% of the total diary energy consumption(Franco, Velásquez, & Olaya, 2008) , reason why the self-consumption percentage was chosen as 25% in the economic evaluation of the solar calculator.

2.4.2 Economic Evaluation

For the financial PV system evaluation, some economic parameters must be considered as the electricity cost growth. It includes a 7% inflation rate which is a conservative scenario considering the recent raise of electricity cost in Neiva that has reached 8 – 10 % in the past 6 months. In addition, the PV panel degradation is a crucial factor for the economic evaluation. The annual PV panel degradation rate taken was 0.6% as it is shown in the PV panel datasheet conditions.

Another fundamental parameter is the installed Watt price, which allows determining the PV system cost. There are two types of costs for PV system: Hard cost and soft cost. The first is related to the highest costs like solar panels, inverter and other electrical components. The second is related to the price installation. In Colombia, the hard costs are the same as worldwide prices (high quantity importations), whereas the soft costs are cheaper compared to developed countries. Therefore, \$ 1.8 USD is considered in the algorithm as the Watt installed price.

2.4.3 Cash Flow and Savings

With input data, the simulator estimates the numbers of panels, power energy, inverter capacity and the total cost of the energy system. The cash flow is determined by the period of target PV run life (25 years), where the initial cost is the value for the year when it is equal to zero. The mathematical expression is presented in eq. 1(Wiley&Sons, 2016).

$$F_t = E_P * \eta_{red-FV} * C_{kwh} * (1 + inf)^t \tag{1}$$

Where:

E_P : Annual energy production to PV system

η_{red-FV} : Decreasing in performance PV panel. It is represented by: $\eta_{red-FV} = 1 - dec_{FV}$

dec_{FV} : PV panel degradation (0.6 %)

C_{kwh} : Cost of energy (USD/kWh)

inf: The energy inflation rate (7 %)

t: Time in years

The next step is to calculate the cumulative cash flow which can be calculated following the eq. 2.

$$F_{tac} = \sum_{i=0}^n F_{ti} \quad (2)$$

Where:

n = 25 years (Target PV module)

i = initial year,

Where *i* = 0 then cash flow is equal to -*C_i*, *C_i* is the cost of the system.

The PBP is determined by an iterative cycle where the main aim is to find the year when the cumulative cash flow is positive. For that, the simulator creates a matrix with the values for 25 years, the values of decreasing in performance PV panel, cash flow and cumulative cash flow. Finally, the algorithm considers interpolations when is necessary.

2.4.4 Investment Returns

The evaluation of investment return was measured by the rate of return on investment (IRR) and the net present value (NPV). In this case, the investment is the total cost of the energy system. These variables have related each other to the eq. 3 (Wiley&Sons, 2016).

$$NPV = -C_i + \sum_{t=1}^n \frac{F_t}{(1 + IRR)^t} \quad (3)$$

Where:

VPN: The net present value

C_i: Initial cost, Total cost of system

F_t: Cash flow at time *t*

IRR: The rate of return on investment

t: Time in years

n: Target PV module, 25 years

To estimate the value of IRR is common to use an approximation of Schneider based on binomial theorem as it could be seen in the eq. 4 (Wiley&Sons, 2016)

$$-C_i + \sum_{t=1}^n \frac{F_t}{(1 + IRR)^t} = 0 \quad (4)$$

To estimate the IRR value, an option is using a numerical solution with methods available in investigations on this field.

The process followed in the algorithm is to give values for IRR initial, the rate of rising and accuracy. In the same way, it will calculate values and difference between them. The procedure is performed by iterative cycle until the accuracy will be less than 1×10^{-5} . Finally, the NPV value is calculated by eq. 3.

2.5 Software Algorithm

A beta version simulator was developed to calculate the size of PV System, costs and IRR, the PBP and the NPV for residential and commercial facilities, based upon user inputs. Flow chart diagram is shown in Figure 2.

The steps for calculation were coding in PHP programming language for sizing and economic evaluation for the grid-tied system. To log in, the application has a user module with easy access in, where the users have the capability to bring their average cost of the electricity bill and their social stratification tier as inputs to determine

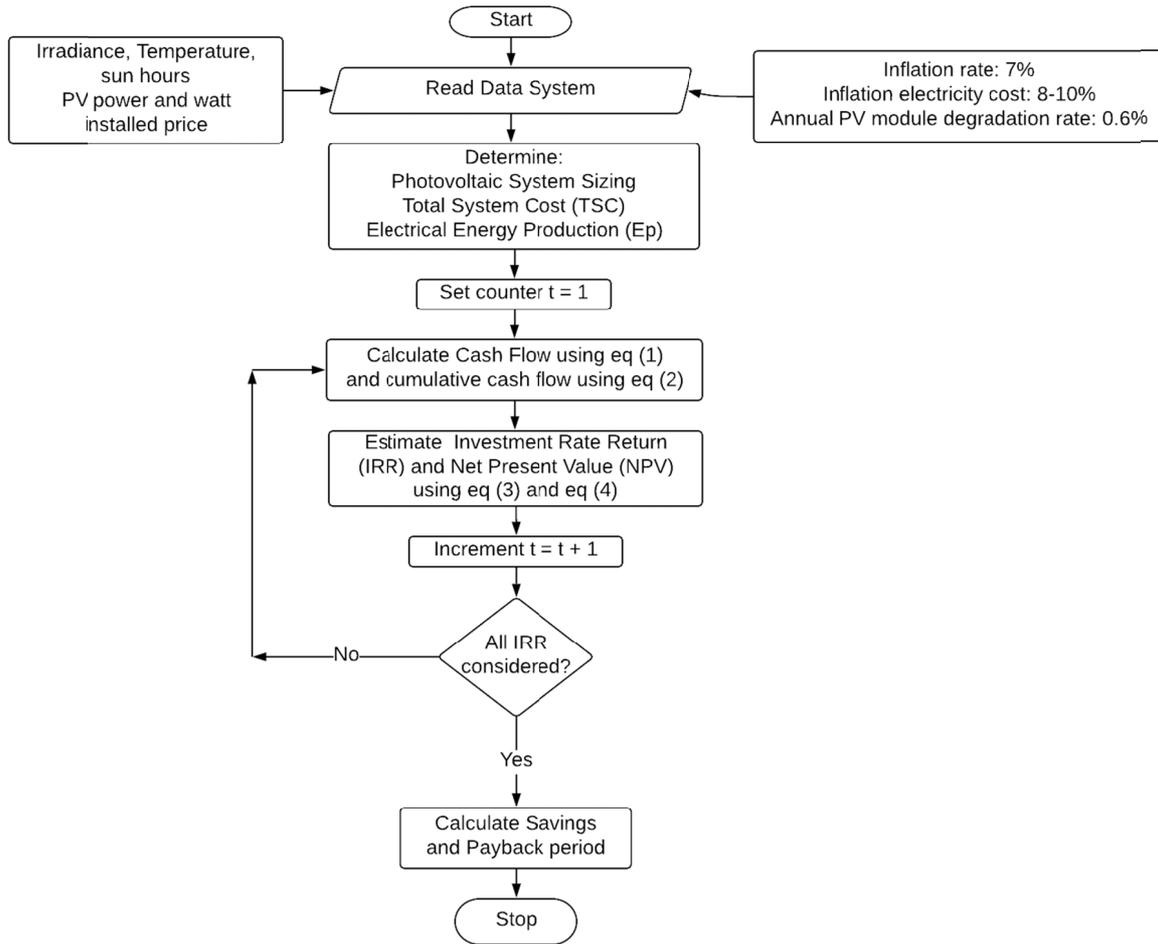


Figure 2. Flow chart diagram for software algorithm

the size and financial calculations for the PV system.

The web application offers to the user an easy tool to know the PV size, cost and financial performance. The user’s data is sent to the simulator, where is taken as initial parameters to determine the economic analysis according to the administrator input, PV coverage percentage (self-consumption), inflation rate, annual panel degradation rate and the diary energy PV panel generation. All these settings are based on previous studies related to the current energy and economic background.

The web application has an interface and it is shown in Figure 3, where the user must fill out the information to estimate the PV System.

Figure 3. Calculation section

3. Results

3.1 Solar Potential

The solar resource was obtained based on data from NASA(Nasa, 2011) for the place of interest Figure 4 shows the solar radiation for a year where average value is near to 3.9 kW/m².

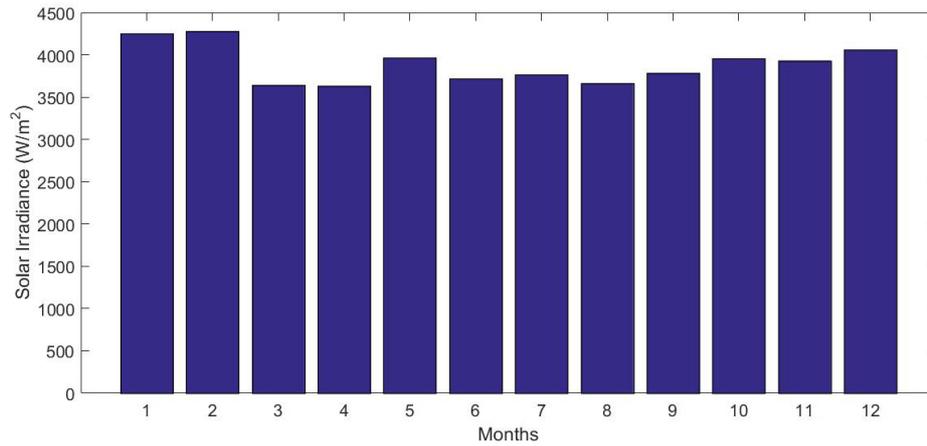


Figure 4. Solar Irradiance for Neiva, Colombia. Data from NASA (Nasa, 2011)

3.2 Energy Generation

The data was measured and recorded from February 2015 to February 2016. The results obtained for July are shown in Figure 5 which delivers an average power generation of 4.43 kWh/day for the installed PV system. This information is used to determine the PV system size into the simulator, and it is updated every month with the monthly electricity cost company report.

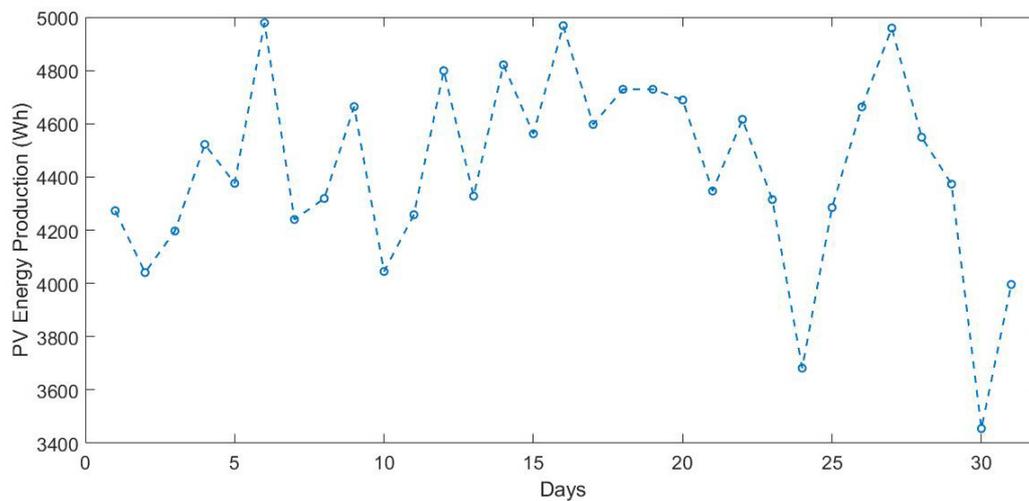


Figure 5. Energy production. July 2016

3.3 Trend Electricity Price

Every socioeconomic stratum has included the respective subsidies, contributions and street lightning rate, which is considered in the algorithm. Table 1 shows the electricity cost per social stratification.

Table 1. Electricity cost per social stratification.

Socioeconomic Stratum	Average electricity cost (cent USD \$/kWh)
1	7
2	8
3	14
4	15
5 - 6	18

3.4 Software

The simulation results show the PV system size with the number of PV modules and the rooftop area required. Additionally, it shows the cost of the system, the economic evaluations, the IRR, the PBP, and the NPV. The information is studied by the user to determine the system viability. The environmental impact is shown with some statistics that reflect the benefits in developing the PV system.

3.4.1 Simulation Results

The proposed algorithm is tested for a residential case with socioeconomic stratum 3 in the city of Neiva Colombia as it can be seen in Figure 6.

Figure 6. User data interface

The results show the system specifications: size, number of panels, rooftop area and these are shown in Figure 7 whereas Figure 8 and Figure 8 illustrate the economic evaluation results and the environmental impact during the life cycle of the system (25 years).

SOLAR REPORT

ENERGY POTENTIAL

Juan esteban Arenas
 Neiva
 Calle 58 # 21-12



3 Stratum	7 Panels
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Technical Data

The following information is the result of financial analysis performed by the Computer Tool.

Number of modules	16
Total Power to Install (kW)	4
Module Power (W)	250
Module Area (m ²)	1.6
Total System Area (m ²)	20.8

Figure 7. PV system specification results

Total System Cost

Sell | Rent

\$ 7,200
PV System Cost

\$ 7,200

Total Capital Cost

Monthly Savings

Current electricity payments	\$75.50
PV savings	\$33.73
New electricity payments	\$41.77

Figure 8. Economic evaluation results

Total Savings

Statistical reports

\$ 33.73
Monthly USD savings

208.2
Monthly kWh savings

14.90
Monthly water savings (m³)

11.7

Years
Payback period

\$17,733

Savings in 25 years

Figure 9. Environmental and saving results

The PCS also provides the cumulative cash flow to determine the economic projection as it is shown in Figure 10. The PBP analysis shows that in the 11th year, the initial investment is recovered and in the 25th year, the cumulative savings is around \$17,733 USD.

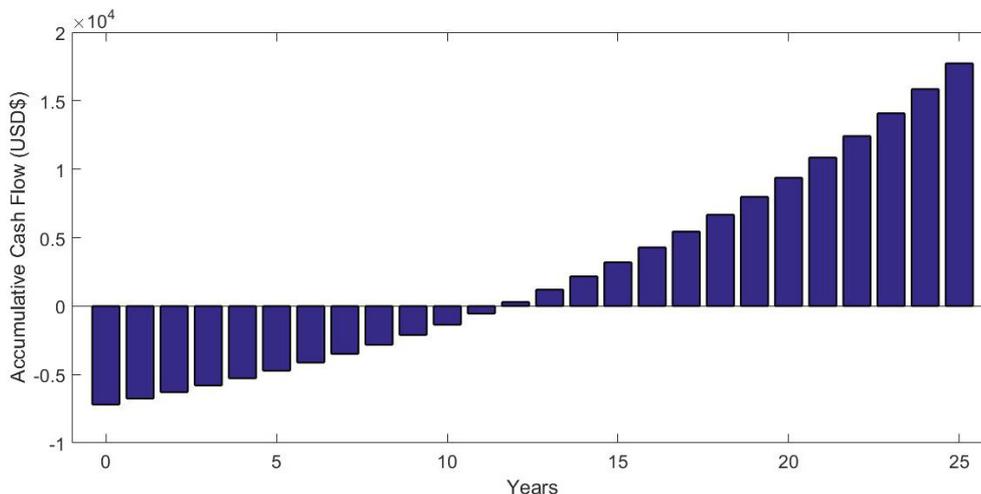


Figure 10. PV system cumulative cash flow

The web application was tested for different residential conditions and the payback period varies between 15 and 7 years according to the social stratification. In the case of the upper stratum, the return on investment is faster because the cost of the electricity price is higher.

4. Discussion

In order to compare the results obtained by the proposed PCS method, two commercial software—Sunny Design and HOMER—are used to evaluate the algorithm operation. The total installed capacity of the system of 4 kW to supply monthly electrical energy consumption was evaluated.

The meteorological characteristics of Neiva; the energy requirements of the house, the energy price and the configuration of PV system, among other information are introduced in the two software previously mentioned. The economic result is shown for both simulators in Figure 11. The initial cost is the biggest one in HOMER series compared with other two. It indicates initial investment is higher than others due to hard cost of equipment considered for that software.

On the other hand, the PBP value illustrates 10 years for Sunny design, 12 years in PCS and 13 years in HOMER. The target life time presents effective savings with values 19000, 17000 and 16000 dollars for Sunny Design, PCS and HOMER respectively. The Upper one is because of the net metering is consider for the cases when the electrical generation is higher than consumption, providing additional saving by the electrical energy injected to the grid. The others don't consider than option causing Sunny Design simulation has more savings and lower Payback Period.

These economic analyses show that PCS, a software adjusted to socioeconomic stratum tariff give a representative evaluation to determine PV System feasibility to perform in Neiva.

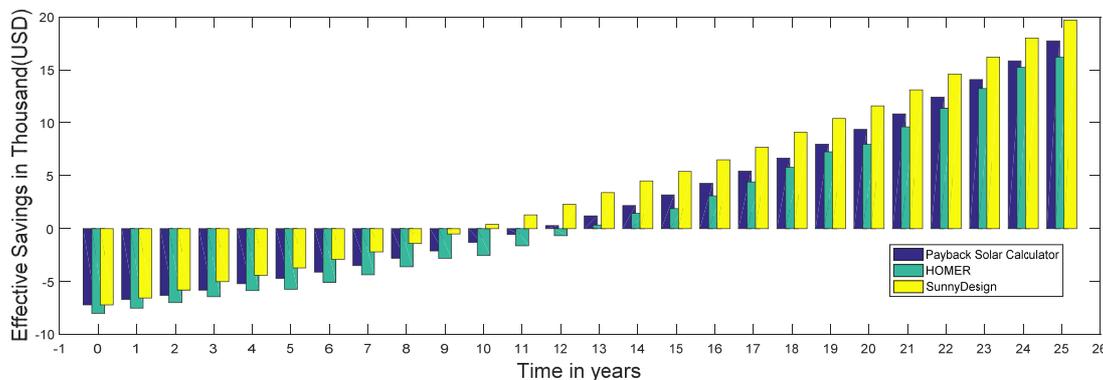


Figure 11. Effective savings for PCS, HOMER and Sunny Design

4.1 Comparisons with Case Study in Norway

The PV system considered for comparison is a study made in the Norwegian University of Life Sciences-Norway (Adaramola, 2015) for a building with total installed capacity of the system of 2.0 kW. The total annual energy production estimated was 1927.7 kWh and total investment was taken as US\$6930. Financial assessment performed for project life of 15 years determined cost of electricity in US\$ 0.333/kWh. Payback period showed 11 years to recover the investment and total savings obtained in US\$7075 by the same time. For this economic analysis, the interest rate is taken as 6.0% while the inflation rate of 2.0% is used.

The same installed system was evaluated in PCS software. It found initial capital cost in US\$4000, output electrical production in 1424 kWh per year, PBP value of 8 years and effective savings in US\$5904. In this study case, the cost of energy calculated varies between US\$0.16 to US\$0.18/kWh. Savings differences in both cases is due to interest rate and inflation rate; which in Neiva city is higher than Norway, 10% and 7% respectively.

5. Conclusions

In this study is proposed a Payback Calculator Software (PCS), an application to economic assessment of grid tied PV system for residential applications. The algorithm performed is composed by a procedure that include user's socioeconomic stratum in the cost of electrical energy. Additionally, the computer tool takes in account production data of 1 kW PV system installed that makes results more accurate. The PCS is compared with other two (2) commercial software to show the reliability on its results.

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