

## Renewable microgrid operational results and economic evaluation using RETScreen<sup>TM</sup>

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### ABSTRACT

This article describes the performance results of the first renewable microgrid of Chocó, Colombia, monitored over two years (2016-2017) adding an economic approach. A virtual platform is used to analyze, in real time, the microgrid power production, while a meteorological station measures the solar irradiance and the ambient temperature. The results indicated that the generation of AC PV energy was 21,817 kWh/year on 2016 and 23,301 kWh/year on 2017. The photovoltaic system's average efficiency was 10.3 % on 2016 and 11.09 % on 2017. An economical analysis of the renewable microgrid is also presented using RETScreen<sup>TM</sup> software. The results show a net present value of \$237,028 USD for an evaluation period of 25 years with annual energy savings of \$4,622 USD. A calculation on greenhouse gas emissions show that 22.9 tCO<sub>2</sub> per year are avoided when using the solar energy tech.

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## 1. INTRODUCTION

With the increasing concerns regarding energy reliability and emissions, the claim on self-generation and the distributed energy resources are increasing accordingly. Two-thirds of all fuel used to produce power electricity is mostly wasted by emitting unused thermal energy from a power generation system into the air or into water streams (e.g. sea and river) [1].

Micro Grids (MGs) are expected to achieve many advanced abilities for utility, such as active/reactive power supporting, customized power quality and reliability, black start, and so on. Therefore, several countries and organizations have carried out many demonstrations to verify the micro grid concept and its advanced abilities [2].

A new season has begun for power generation at high efficiency in power systems by the initiation of innovation in Renewable Energy Sources (RESs) and Distributed Generation (DG) sources. As a consequence, different RESs and DGs are used in small scales in MGs [3]. Increasing the use of renewable energy and DG sources of high efficiency in power systems has provided new points of view. This new viewpoint, i.e. generation units generating power in a smaller scale, is close to consumers in the MGs [4].

In general, the energy infrastructure of a micro grid can vary depending on the geographical conditions, availability of the type of generation systems, and socio-economics such as acceptability, availability, and accessibility. For example, micro grids can be developed with no renewable energy sources in

regions where renewable energy cannot be harvested, while the micro grids in regions with abundance of sun light can be primarily built upon the Solar Photovoltaic renewable energy [5].

Many studies have been devoted to research the performance and modeling of renewable systems [6-17], but there is a problem: there isn't enough performance information for microgrids operating in tropical countries, where there are high potential of solar irradiance and wind velocity. Moreover, there isn't specific economical analysis about microgrids that allows to know the total investment and the recovery's time of that investment. The novelty of this paper is that it is reporting the technical performance of the first renewable micro grid of Chocó, Colombia and its detailed economic analysis, including the CO<sub>2</sub> avoided emissions.

## 2. MICRO GRID'S DESCRIPTION

The microgrid is composed of a photovoltaic system with 80 polycrystalline silicon modules (Amerisolar ASP-6P30), 250 W each, installed in the roof of the Building of Renewable Energy of Chocó – CERCHOCO – Andagoya, Colombia. Figure 1 shows the photovoltaic generator.



Figure 1. Photovoltaic system of 20 kW installed in Andagoya - Chocó, Colombia

Table 1 shows the data sheet of the PV modules used as photovoltaic generator. The photovoltaic generator connects to the grid using a 20 kW (STP 20000TL-US) dc/ac inverter. Table 2 shows the STP 20000TL-US inverter's technical data.

Table 1. Electrical Specifications of the PV Modules

Electrical Data – STC PV MODULE	Amerisolar ASP-6P30
Nominal Maximum Power (P <sub>max</sub> ) [W]	250
Optimum Operating Voltage (V <sub>mp</sub> ) [V]	30.3
Optimum Operating Current (I <sub>mp</sub> ) [A]	8.26
Open Circuit Voltage (V <sub>oc</sub> ) [V]	38
Short Circuit Current (I <sub>sc</sub> ) [A]	8.75
Module Efficiency (η) [%]	15.37

Table 2. Technical Data of the PV Inverter

Technical Data	Sunny Tripower 20000TL-US
Input (DC)	
Max. array power	30000 Wp STC
Max. DC voltage	1000 V
MPPT operating voltage range	150 V – 1000 V
Max. operating input current/per MPP tracker	66A / 33A
Output (AC)	
AC nominal power	20000 W
Output phases / line connections	3 / 3-N-PE
AC voltage range	160 V – 280 V
Max. efficiency	98.5%

Because the voltage required by the inverter to activate its maximum power point circuit (VMPP) is in the range 320 - 800V, the 80 modules were connected using four (4) branches in parallel with 20 modules in series per branch. In this way, the total photovoltaic array power is 20 kW.

A backup energy system was installed, composed of 132.7 kWh battery bank (48 Sunlight batteries OPZS 2765) connected to the grid through 6 SMS Sunny Island ac/dc inverters (220 Vac, 60Hz) [18]. The battery bank is divided into two sets, each with 24 batteries connected in series. In Figure 2 is possible to see the battery bank and the islanded inverters.



Figure 2. Installed battery bank and islanded inverters

Solar radiation and ambient temperature are measured through a Davis Vantage Pro 2 Wireless weather station, located near the PV generator. The recording of these measurements is done every minute for the entire year 2017.

The sensors' technical specifications are as follow:

- Solar Radiation: A Hukseflux Thermal Piranometer model with a measurement range of 400 – 1100 nm and a sensitivity of 15  $\mu\text{V}/\text{W}/\text{m}^2$ .
- Environment temperature: a 083E-L device with a 10 k $\Omega$  NTC thermistor was used at the standard temperature of 25°C. The electrical resistor variation of this device, in function of temperature, has a measuring range from -50°C to 50°C and a precision of 0.18°C.

The DC and AC signals digitized by the inverter were used in the computer to analyse them. To do this, a device called "Sunny Webbox" was implemented, which is a communication interface that connects the inverter of the PV system to the Internet and to the computer (through the RS485 port). Once the information is obtained, it can be downloaded to a computer, in CSV or XML format [18].

### 3. RESULTS AND DISCUSSION

#### 3.1. Micro Grid Performance

The micro grid's energetic performance is directly affected by the solar radiation and the ambient temperature available at the installation site.

Figure 3 shows the results of the power generation of the photovoltaic array and the generation of AC power at the output of the 20 kW inverter for the years 2016 and 2017.

The energy generation of the micro-grid was greater in 2017 than in 2016, due to the fact that during the last year there was greater solar radiation in Andagoya.

The average DC power generation in 2017 was 2918 kWh/month, with a maximum of 3606.13 kWh/month in the month of September and a minimum of 2141.27 kWh/month in November. In 2016, the average DC power generation was 1942.3 kWh/month. The total DC energy produced in 2017 was 35016.06 kWh/year and 23307 kWh/year in 2016.

The average AC power generation in 2017 was 2145.38 kWh/month, with a maximum of 2616.54 kWh/month in the month of March and a minimum of 1464.71 kWh/month in November. In 2016, the average AC power generation was 1818 kWh/month. The total AC energy produced in 2017 was 25744.6 kWh/year and 21817 kWh/year for 2016.

The low levels of AC energy shown in Figure 3 are caused by losses in transportation between the array and the PV inverter, and by low solar radiation days as well, due to rain seasons in the country. Figure 4 shows the variation of the efficiency of the photovoltaic generation, the efficiency of the inverter and the efficiency of the complete system.

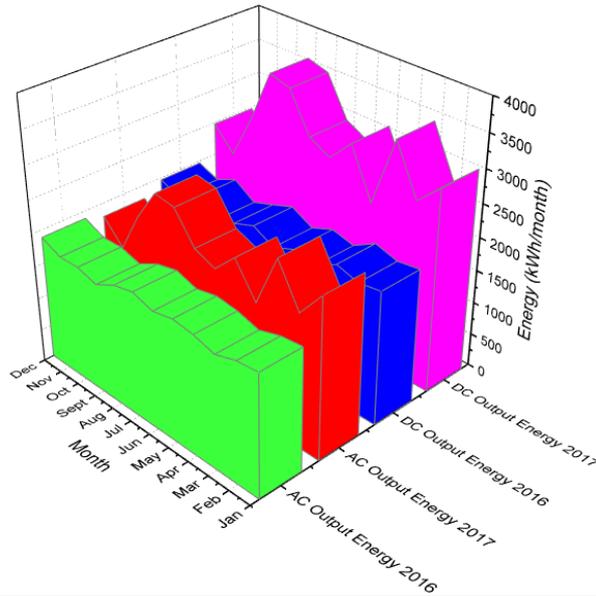


Figure 3. Power generation of the PV array (DC) and power at the inverter output (AC) for 2016 and 2017

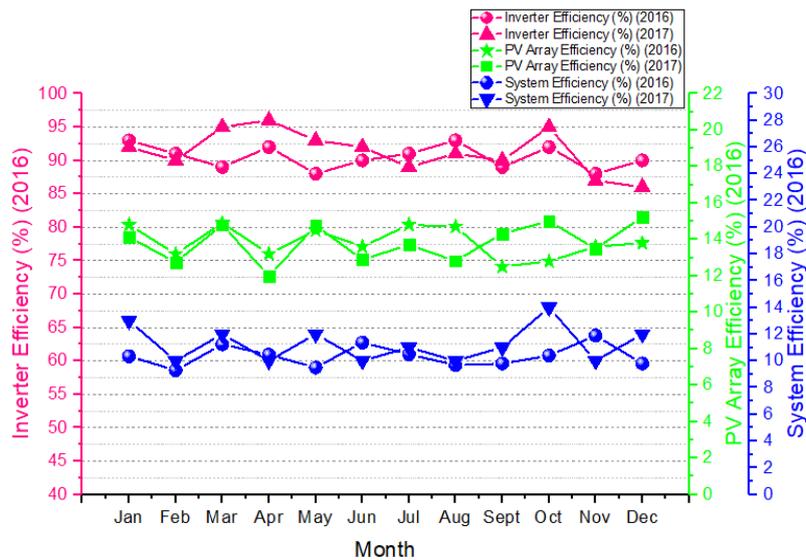


Figure 4. Efficiency profiles of the PV generator, the DC / AC inverter and the complete system for 2016 and 2017

The efficiency of the PV array is calculated as the quotient between the DC power and the incident power of the solar radiation on the solar panels. The efficiency of the inverter is calculated as the quotient between the DC power and the AC power and finally the power of the whole micro-grid (system) is evaluated as the quotient between the AC power at the 20kW inverter output and the incident power of the solar radiation on the PV generator. In this way, this last efficiency includes all the electrical losses of the PV generator, the inverter and the wiring.

The PV array efficiency recorded an average of 13.87% for 2016; with a minimum of 12.5% in the month of September; and a maximum of 14.9 % for the month of March. For 2017, the efficiency of the PV array was on average 13.82% with a maximum value of 15.2% in the month of December. The results reveal a monthly average inverter efficiency of 95.7% for 2016 varying between 92.1% and 97.5% and a monthly average inverter efficiency of 91.33% for 2017 varying between 86% and 96%.

For the system efficiency in 2016, the most representative months were June and November with values above 11%, while the lowest months were February, May and August with values that ranged between 9% and 9.5%. The whole system average efficiency was 10.3 for 2016. For 2017, the average system efficiency was 11.09% with a maximum of 14% in the month of October, a minimum of 10% in 5 months of the year.

### 3.2. Economic analysis using RETScreen™

In order to carry out the economic analysis of the micro-grid, the location coordinates of Andagoya, Medio San Juan in Colombia must first be established in order to know the variables of solar radiation and ambient temperature. Figure 5 shows the meteorological data of the region of interest using the RETScreen™ software.

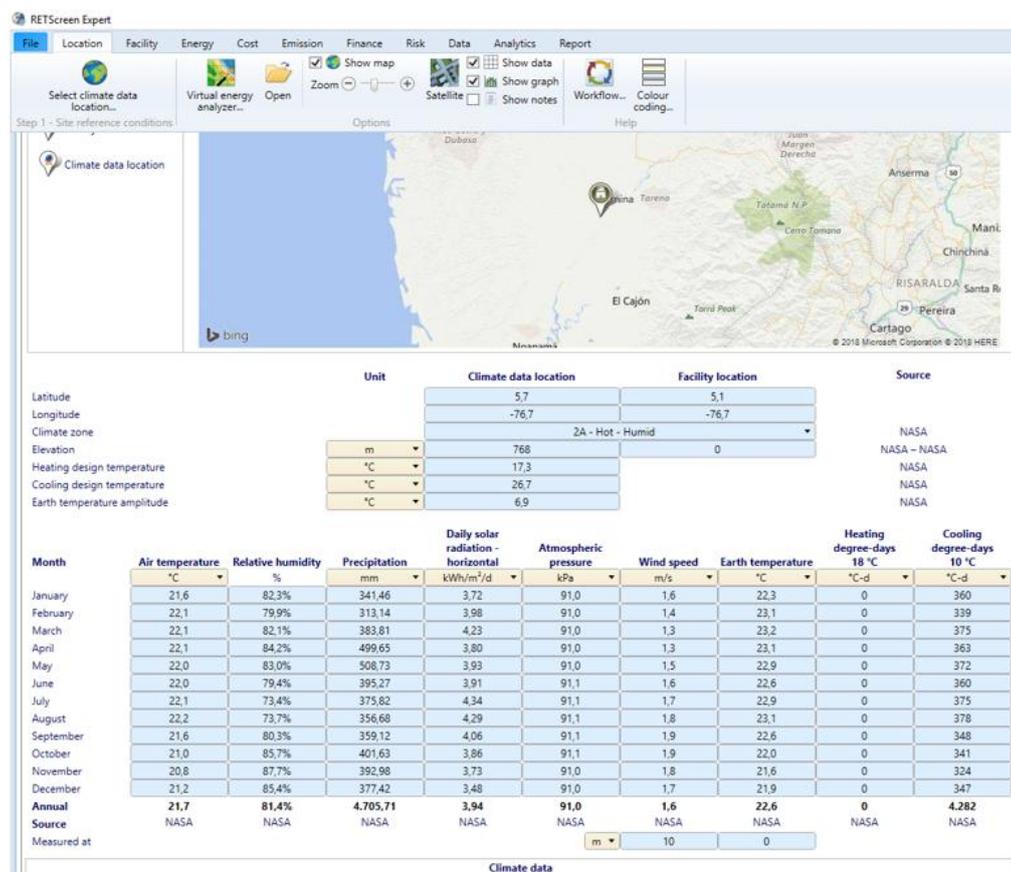


Figure 5. Weather data for Andagoya, Medio San Juan, Colombia

According to Figure 5, which data are measured by NASA, in Andagoya there are 3.94 kWh/m<sup>2</sup>-day of solar radiation and an average of 21.7 °C of ambient temperature.

The second step to simulate the financial behavior and emissions of gases in RETScreen is to detail the power model of the micro grid. Figure 6 shows the technical specifications of the installed micro-grid.

The technical data of the generator selected through the RETScreen software library are as follows: 80 solar panels of 250Wp for each panel selected of the polycrystalline type, for a total of 20 kW in net capacity and with an efficiency of 15.4% per panel. The selected inverter has a capacity of 20 kW and an efficiency of 98%. Both devices have a 10% in losses.

The costs associated with the stages of the project are: system design, procurement and purchase of materials and equipment, implementation and operation and maintenance.

The total cost of the 20kW project was USD 126,344 (1 USD = 3000 COP), with the following characteristics:

- Initial costs: Feasibility, development, engineering, power system and contingencies. This value is \$126,011 USD corresponding to 99.73% of the project.

b) Annual costs: These are associated with the operation and maintenance (O & M) of the system, with an annual projection of \$333 USD. In this way, the implementation costs per kW are approximately \$6,300 USD. Figure 7 presents the energy exported to the electricity grid

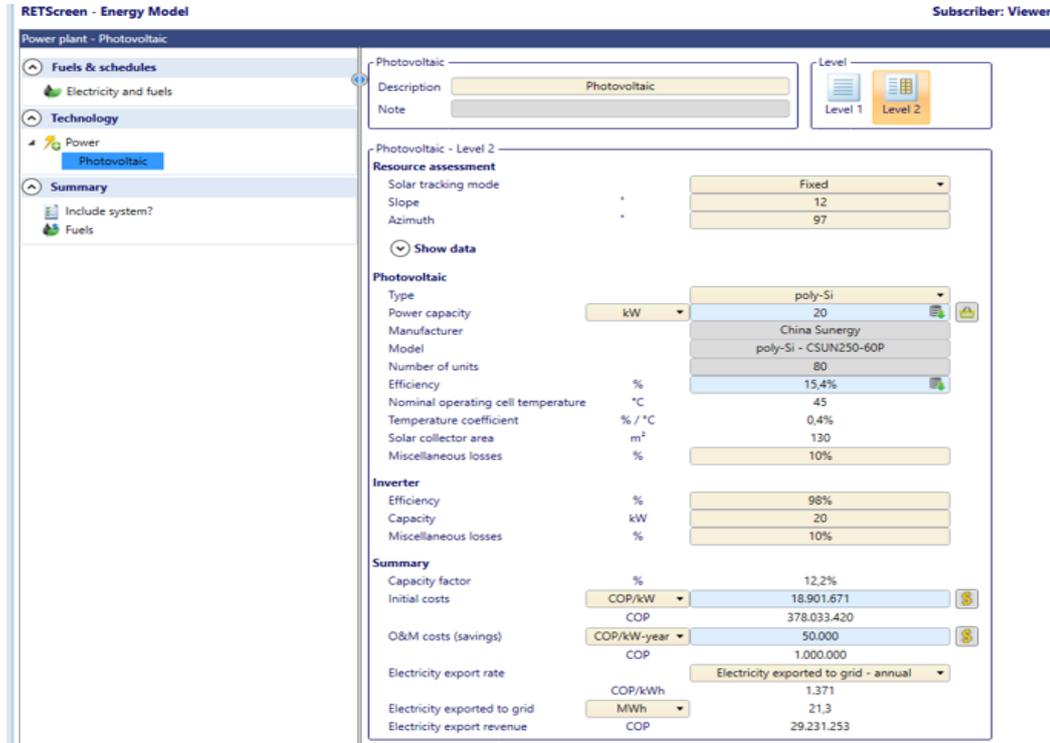


Figure 6. Technical specifications of the micro grid in RETScreen

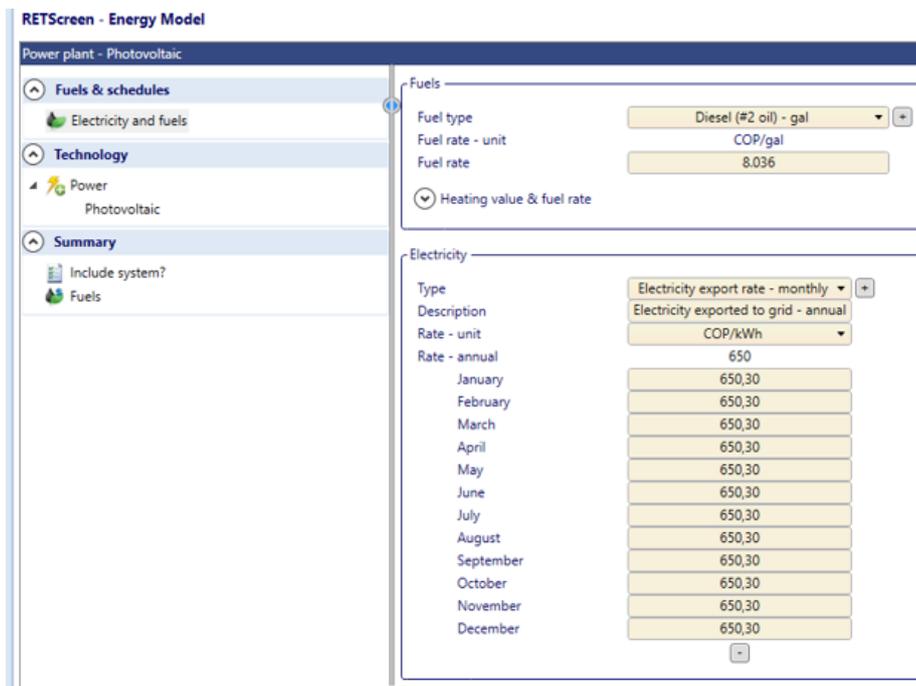


Figure 7. Energy exported to the network by the micro-grid

The energy accumulated during the first year of registration was 10,153 kWh. This reflects the reliability and certainty of the analysis carried out by RETScreen. Figure 8 shows the analysis of the CO2 emissions avoided by the installation of the micro-grid.

The analysis of emissions is carried out comparing a base case of electricity generation with coal. This case generates an emission factor of 1,074 tCO<sub>2</sub>/MWh and its total contribution is 22.9 tCO<sub>2</sub> for the 21.3 MWh generated with that fuel. Thanks to the use of panels, the emission factor is 0.0 tCO<sub>2</sub>/MWh and the contribution is 0.0 tCO<sub>2</sub> for a generation of 21.3 MWh. The reduction of the total annual emissions is 22.9 tCO<sub>2</sub>, equivalent to 9839.2 liters of gasoline not consumed. Figure 9 shows the analysis of the accumulated cash flow for the implemented microgrid.

The cost of the period refers to the projected costs in the year, from where the life or replacement of involved parties is determined. In this case, the life of the inverter is 12 years. The projection for the cost of the inverter at 12 years was \$6,635 USD.

The export rate analyzed is \$0.46 USD. The economic investment for the project is \$126,344 USD and its repayment period occurs in 9.8 years and the energy savings for the generation and/or annual sale of energy is 21 MWh. Then, every 12 years a small valley is reflected due to the replacement of the inverter and other components of the system. The net present value for the 25-year project is \$237,028 USD. This reflects that the investment in the generation system based on photovoltaic energy is feasible with a margin after 9.8 years of operation.

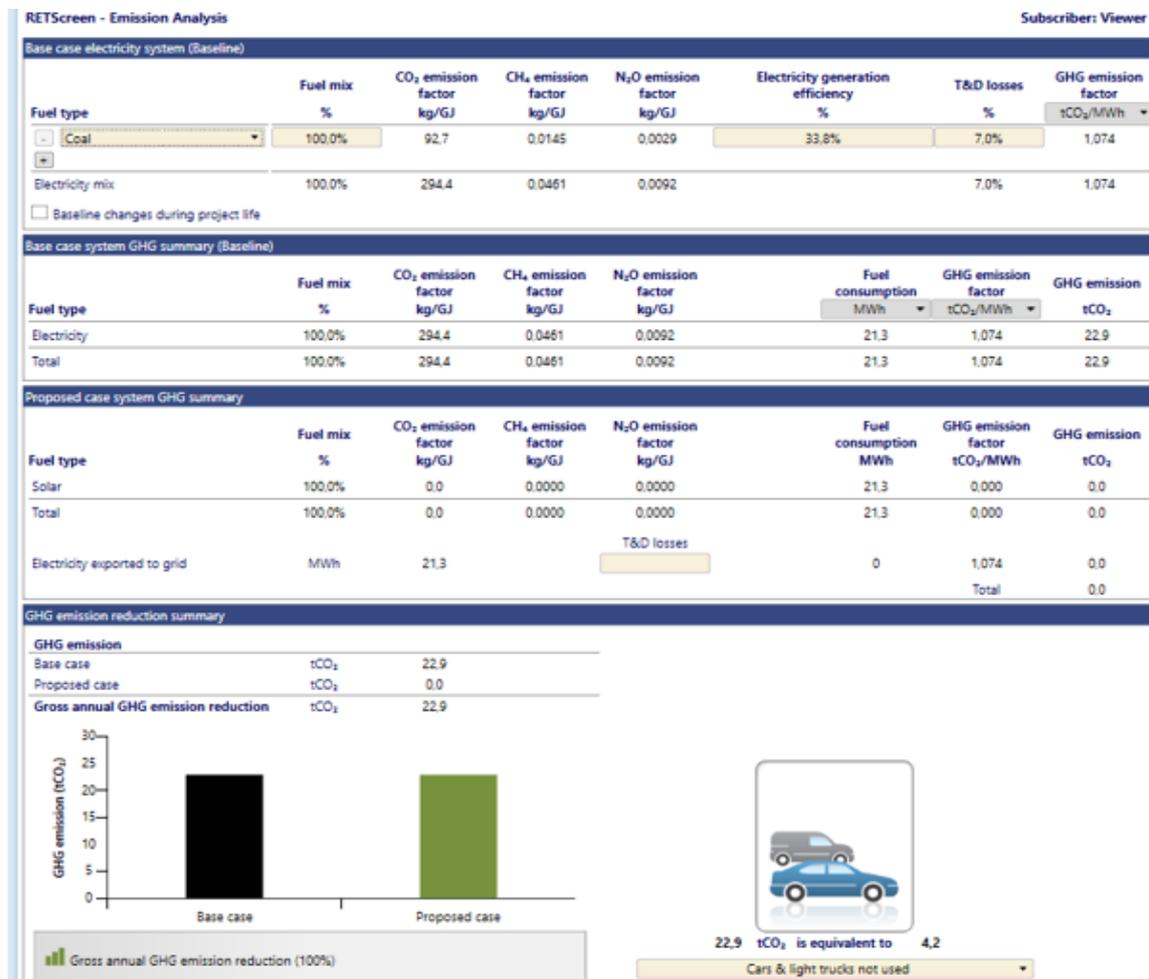


Figure 8. Analysis of CO2 emissions avoided by the micro-grid

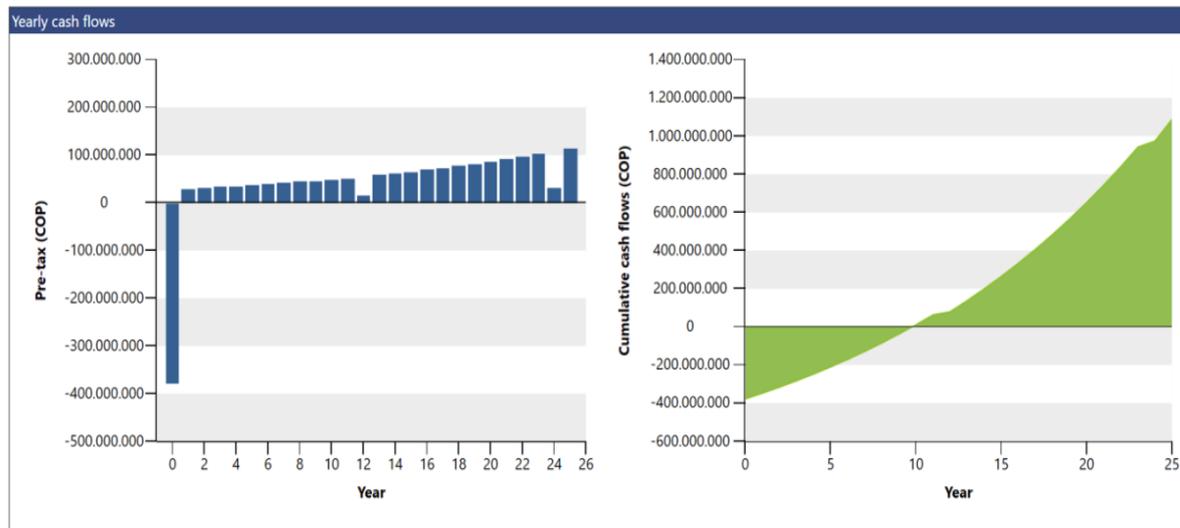


Figure 9. Annual accumulated cash flow analysis

#### 4. CONCLUSION

This paper presents the results of the energy performance of the first micro-grid in Chocó, Colombia. This micro grid has allowed to reliably deliver renewable energy to the inhabitants of Andagoya. Thanks to the excellent solar radiation conditions of the region due to its location in a tropical zone, the microgrid exceeded the power generation during the first two years of operation.

The total generation of AC energy was higher in 2017 than in 2016 due to the fact that the rain conditions in the region were greater in 2016.

The total efficiency of the micro grid was 10.3% in 2016 and 11.09% in 2017. These low values are the result of including in the calculations the losses of the PV generator, the energy transformation of the inverter, the wiring and the effect of the ambient temperature on the solar panels.

The present work includes the economic analysis of the installed micro-grid. This type of analysis is a significant contribution, especially in developing countries in which renewable energies begin to enter.

The net present value for the 25-year project is \$237,028 USD. The total recovery of the initial investment is 9.8 years.

Thanks to the use of the RETScreen tool, it was possible to evaluate the environmental impact of the installed micro-grid. In total, the emission of 22.9 tCO<sub>2</sub> is avoided with implementing PV solar energy.

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