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Technical and Economic Feasibility Survey for Wind and Photovoltaic Hybrid Renewable Energy System. A Case Study in Neiva-Huila, Colombia

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Abstract

This research presents a design and techno-economic assessment for implementation of wind & solar hybrid renewable energy system in Neiva city. The study performed an analysis of meteorological variables trend related, for a five years period (2010-2016) supplied by the Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia – IDEAM with the purpose to identify resources potential, beside of electrical requirements summary and energy cost for a node in the residential area. Sizing and evaluation were made by four architectures according to portion of each renewable source. For optimization and sensitive cases simulation were used the Hybrid Optimization Model for Multiple Energy Resources – HOMER software. The most reliable option was just for a photovoltaic solar source and no-available one the wind option due to the resources boundaries (wind speed less than 2 m/s). The results showed a major reliability from solar energy with an output power in 7475 kWh-year, cost of energy in 0,14 $USD/kWh and the less total cost in $1956 USD giving participation of 65% in daily consumption.

Keywords. Wind & solar renewable system, photovoltaic module, reliability analysis, HOMER simulation, cost of energy, electrical daily requirement

Nomenclature

G is the monthly radiation
A_{pv} is the area of the photovoltaic module
η_{PV} is the efficiency of the photovoltaic module
η_m is nominal efficiency of the module
η_{PC} is the efficiency of the power equipment
β is the temperature coefficient
T_c is the temperature of the cell
T_r is the reference temperature
E_L is the daily energy consumed
G_{input} is the daily solar energy W/m^2
η_{PV} is the efficiency of the photovoltaic module
η_{out} is the inverter output efficiency
TCF is the temperature correction factor
E_{wp}: Wind energy
P_t : Turbine power
hr : Average hours of resource availability
C_p : Capacity factor 20 - 50%, maximum 59%
N_C is the maximum number of days of autonomy
E_L is the energy required daily
DOD is the depth of discharge of the battery
η_{out}, is the output efficiency calculated from

$$\eta_{out} = \eta_B * \eta_{INV}$$

η_B is the efficiency of the battery
η_{INV} is the efficiency of the investor
E_L is the load demand (W)
E_{GA} is the total energy generated (Wh)
E_B the battery charge in Wh
E_{Bmin} is the minimum battery bank charge in Wh.

Introduction

There are several current concerns of the Colombian population such as climate change and the environmental consequences that it brings to the different planet earth ecosystems. In contrast, government entities are joining efforts to include activities in their development plans in favour of contributing to the greenhouse gas emissions (GHG) reduction associated with the energy generation that cause an increase in global average annual temperature.

Thus in Huila, a department located in southern Colombia, the Government and the Regional Autonomous Corporation of Alto Magdalena-CAM came together to create a program named HUILA 2050 CLIMATE CHANGE PLAN, which incorporates actions to be carried out in sectors such as energy, industrial, agricultural and final disposal of waste; with the objective of implementing strategies that reduce GHG [1]. Similarly, the internal Agenda-Regional Plan for

Competitiveness of Huila [2] and Law 1715 of 2014 by the Ministry of Mines & Energy [3], promote the conventional energy matrix diversification with the implementation of renewable energy sources known as Non-Conventional Sources of Energy or Renewable Energies, where it is pertinent to mention solar, wind and biomass use.

Although according to the studies reported in the radiation atlas conducted by the Institute of Hydrology, Meteorology and Environmental Studies IDEAM [4], the department has an abundance of solar resources ranging between 4.5 and 5.0 kW/m^2 average daily monthly availability of energy, there are no known feasibility studies to determine whether solar energy is favourable or not for Huila's diversified energy market and whether it contributes to mitigate environmental impact. The same situation arises for wind energy and biomass, as well as for hybrid or combined systems between these energy sources.

Some studies in the international field have carried out revisions related to the technical and economic feasibility of the wind-solar hybrid energy systems implementation, providing optimal sizing techniques that consider changes in local meteorological conditions such as solar radiation, temperature and wind speed. Economic and technical evaluation methods include Reliability Analysis, analysis of the Loss Power Supply Probability - LPSP, Annualized Cost Analysis - ACA, cost analysis Level of energy and iterative optimization techniques; they have been used for evaluation and simulation [5]–[12]. In Colombia, researchers have studied the feasibility of implementing energy systems of this type in isolated areas to identify the resource potential and the limits on its use [13]–[15].

This study presents the process to evaluate the potential of the renewable resource and the technical and economic feasibility of a residential hybrid energy system in Neiva. Statistics was applied for a period of 5 years (2010-2016), an integrated methodology resulting from the synthesis of the most relevant techniques analysed in the literature and simulations of optimization cases with the HOMER software, were carried out to identify the most viable setting.

Methodology

The methodology used was constructed based on techniques and research expressions in the area that correlated with the study area. The availability identification of the resource as the energy requirements was carried out initially; followed by system dimensioning and financial evaluation; later a reliability analysis and finally an optimization simulation.

1.1 Scope study

The city of Neiva, capital of the department of Huila is located at coordinates 2 ° 55 '39 " N and 75 ° 17' 15" W, at a height of 442 meters above sea level with a population of 345,911 inhabitants and an area of 1,557 km^2 [16].

For the climatological variables analysis, the information provided by the Institute of Hydrology, Meteorology and Environmental Studies of Colombia –

IDEAM, supplied from the monitoring stations closest to the research node. Table 1 shows the coordinates of the points examined in the investigation.

Table 1. Points examined in research.

Node of study	Latitude	Longitude	Altitude
Hacienda Manila Station	3.1301	-75.0812	566.8
La plata automática Station	2.3333	-75.8335	2114
Benito Salas Station	2.9493	-75.2936	446
Study node	2.9509	-75.2957	442

1.2 Renewable resource potential

The availability assessment of natural resources from a renewable source to generate electric power was carried out using descriptive statistics. Information processing was done for the following meteorological variables: solar radiation, wind speed, temperature, precipitation and solar brightness. Study area patterns were identified, as well as useful average trends for the sizing of the hybrid system.

1.3 Energy requirement

For the study node, a characterization of the trends related to electricity consumption, the tariff and the cost paid for the same concept was made. Based on this, a monthly average consumption was established, and a daily electric charge profile was defined.

1.4 Technical Evaluation

A solar&wind hybrid system consists of a photovoltaic array, a wind turbine, a battery bank, an inverter and a charge controller. Figure 1 presents the position of each component in the proposed model.

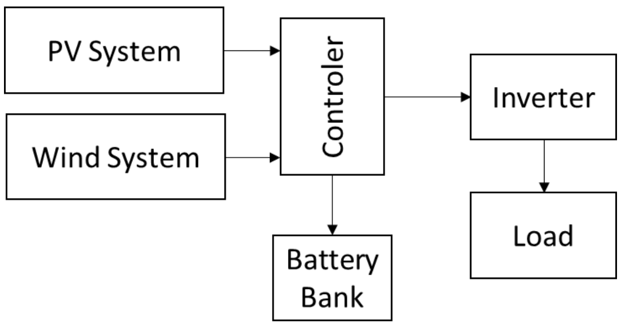


Figure 1. Hybrid system diagram

For the general architecture, 4 scenarios were proposed according to the percentage of electricity supply from each source, which can be observed in Table 2.

Table 2. Hybrid System Settings

Settings	% Solar (PV)	% Wind (WP)
1	80	20
2	50	50
3	100	0
4	0	100

1.4.1 Solar component sizing

The energy produced from a PV system with area A_{pv} (m^2) is given by equation 1 [5]:

$$E_{FV} = G * A_{pv} * \eta_{PV} \tag{1}$$

The efficiency of the module calculated with the equation 2.

$$\eta_{PV} = \eta_m * \eta_{PC} * [1 - \beta(T_c - T_r)] \tag{2}$$

The number of photovoltaic modules (N_{pv}) is determined from the relationship in the equation 3 and 4 [17]:

$$N_{pv} = \frac{PV_{Peak\ power}}{Peak\ power\ \ PV\ module} \tag{3}$$

$$PV_{peak\ power} = Area\ of\ a\ PV\ array * PSI * \eta_{PV} \tag{4}$$

Where PSI is the maximum radiation intensity taken as 1000 W/m^2.

The size of the array can be calculated with equation 5 [17]:

$$\boldsymbol{Area\ of\ solar\ PV\ array} = \frac{\boldsymbol{E_L}}{\boldsymbol{G_{input} * \eta_{BIPV} * \eta_{out} * TCF}} \tag{5}$$

Where E_L is the daily energy consumed, G_{input} is the daily solar energy W/m^2, η_{PV} is the efficiency of the integrated photovoltaic module in the construction, η_{out} is the output efficiency of the inverter and TCF is the temperature correction factor and TCF is the temperature correction factor.

1.4.2 Wind component sizing

The power of the commercial turbine that must be used for the wind system can be estimated from the equation 6:

$$E_{wp} = Pt * hr * C_p \tag{6}$$

Once the turbine power is calculated, it is investigated and the one that is commercially available is determined in accordance with the requirements.

With the processed data of the wind trend: direction and wind speed. The daily energy E_{wp} estimated to produce the turbine under the conditions of the site is calculated through equation 7 [6].

$$E_{wp} = \frac{1}{2}\rho A V^3 \quad (7)$$

Where ρ is the air density, A is the flow area and V is the average wind speed.

1.4.3 Inverter sizing

The selected inverter should be able to withstand the maximum expected energy of DC loads. The output capacity of the inverter must be greater than the power of the total DC loads. The conversion efficiency to the minimum load should be at least 80% [17].

The nominal power of the inverter is calculated from the expression 8, where the power factor is normally provided by the manufacturer.

$$P_{kVA} = \frac{P_{hwfv}}{Power\ factor} \quad (8)$$

The input energy per day to the inverter E_{INV}, where the efficiency η_{INV} is given by the manufacturer as shown in equation 9:

$$E_{INV} = \frac{E_{hwfv}}{\eta_{INV}} \quad (9)$$

1.4.4 Storage sizing

The storage capacity of the battery can be calculated according to equation 10: [6]:

$$Storage\ capacity = \frac{N_C * E_L}{DOD * \eta_{out}} \quad (10)$$

The battery life is a function of the maximum depth of discharge, taken as 0.8. The method for storage design is based on the energy supply concept during the number of autonomous days; during these days the demand for energy is satisfied only with the energy storage system.

If Nc is the largest number of autonomous days, then the minimum hourly amperes of the battery are determined by equation 11:

$$Ah_{totB} = \frac{Storage\ capacity}{DC\ nominal\ voltage} \quad (11)$$

The energy storage capacity of the battery (BA_{Ah}) is determined by the daily energy requirement (E_{inv}) and by the number of days of backup (M_{Backup}) using equation 12, [14]:

$$BA_{Ah} = \frac{E_{inv} * M_{Backup}}{V_{in,DC} * DOD} \quad (12)$$

1.4.5 Design of the battery charge controller

The primary function of a charge controller in an independent power system is to keep the battery in the highest possible state of charge, protecting it from overloading the network and overloading.

The charge controller is generally dimensioned in such a way that it performs its control function. A suitable charge controller must be able to withstand the set current, as well as the total load current and it must be designed to match the voltage of the photovoltaic solar module, wind turbine, as well as that of the battery bank.

The MPPT charge controller is specified according to the voltage handling capacity. Nowadays, the charge controller usually comes with the inverter. There is a recommended voltage range, within which must choose the DC voltage of the power generating system.

1.5 Total Cost of Hybrid System

The first step in the economic evaluation was the determination of costs. These were divided into components, installation and others.

The costs of the components were evaluated including photovoltaic and wind. A synthesis of the cost in dollars was made according to the information availability.

The installation costs are related to construction, civil works, engineering and contingencies; which were calculated from 30% of the cost of each panel and turbine respectively [13].

For other components such as wiring, metal structure, grounding, protection systems, small distribution towers and lifting services; they were estimated with 10% of the global cost [13].

During operation and maintenance, equation 13 was considered to calculate the related costs during such period, taking as an initial point 1% for the photovoltaic component and 3% for the turbines, a value equivalent to the maintenance of the first year.

$$C_{amain}(n) = C_{amain}(1) * (1 + f)^n \tag{13}$$

The dismantling was determined from the methodology of level costs of the International Energy Agency (IEA), where they are estimated at 5% of the cost of installing panels and turbines respectively [13].

Thus, the total cost is determined as the sum of each of the mentioned aspects as can be seen in expression 14.

$$C_{hwfv} = C_{fv} + C_{wp} + C_{inst} + C_{O\&M} + C_{desm} \tag{14}$$

1.6 Economic evaluation

1.6.1 Levelized cost of energy

The system costs analysis also plays an important role in the analysis of a hybrid system. There are several ways to perform a cost analysis for the system. The analysis of the levelized cost of energy (LCE) can be one of them, defined as the relation of the cost of the total annual system C_{A_total} and the energy generated by the system E_{total}, given by the expression 15, [9].

$$LCE = \frac{C_{A\_total}}{E_{total}} \tag{15}$$

Another important factor that they have studied in [10], is the Annual Life Cycle Cost – ALCC, which includes the Life Cycle Cost – LCC, equation 16: [9].

$$ALCC = CRF * LCC \tag{16}$$

Considering the influence of the increase in the cost of annual maintenance and operating costs, the capital recovery factor CRF was used, as shown in equation 17 [9].

$$CRF = \frac{d(1+d)^t}{[(1+d)^t - 1]} \tag{17}$$

Where d is the discount rate that is the profitability that the financial entities offer for capital investment (2.7% taken for this case) and t is the life time of the Project.

1.6.2 Net Present Value – NPV

The net present value as the total present value, which includes the initial cost of the system, the repair and maintenance cost [11]. The NPV compares the present value with the future value, so that inflation is considered (Inflation for the study of 3.17%).

The NPV can be defined with the equation 18 [11]:

$$\mathrm{NPV} = \left[\left(1 + \left(\frac{\mathrm{P}}{\mathrm{A}}\right)\right)^{\frac{1}{\mathrm{q}}} - 1\right]^{\mathrm{q}} - 1 \tag{18}$$

Where $q = \frac{log\left[1+\left(\frac{1}{N}\right)\right]}{\log 2}$, P is the amount to pay, A is the initial cost and N is the number of payments $N = n * 12$.

1.6.3 Payback period

The Payback Period - PBP is calculated by means of the total investment cost divided by the income of the first year by the energy saved, displaced or produced. In the period analysis of investment recovery, the unit of measure is the number of years to recover the investment from the total cost of the system. Projects with short periods are perceived as having low risk [17].

1.6.4 Savings to investment ratio

The savings to investment ratio can be used to compare the savings with the costs of the relative energy system with the alternative energy system. For positive net savings, the SIR must be greater than one. High values of SIR present greater savings relative to investment [17].

1.7 Reliability analysis

The reliability analysis consists in evaluating the system economically and technically at the same time to determine if it is adequate and sufficient for the load requirements that it will make subjected during its period of operation. For this process, the LCE evaluation and Loss Power Supply Probability - LPSP are sometimes used.

There are several methodologies for this purpose: probabilistic, analytical, iterative, graphic, technical optimization and multi-objective, and in general using computerized tools [5]–[9].

1.7.1 LPSP Analysis

Due to the variation of climatic conditions, sometimes the energy produced from renewable sources cannot be estimated correctly, in these cases it is common to use a reliability analysis for the designed hybrid system, which consists in evaluating the Loss power supply probability. This parameter has been studied in [9], [10], [18].

Some studies propose expression 18 for the calculation of LPSP [19], [20]:

$$LPSP = \frac{\sum_{t=1}^{T} LPS(t)}{\sum_{t=1}^{T} E_L(t)} \quad (19)$$

Where LPS (t) is determined with the expression 19.

$$LPS(t) = E_L(t) - (E_{GA}(t) + E_B(t-1) - E_{Bmin}) * \eta_{inv} \quad (20)$$

1.8 Optimization and sensitivity cases

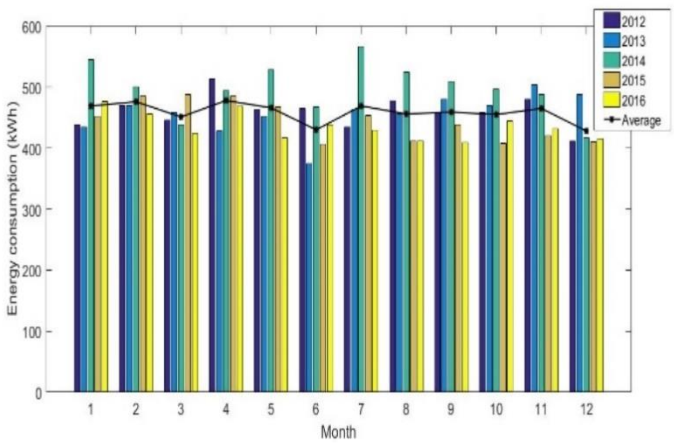
With the information about the meteorological data, the electric charge required and the technical-economic design of the system, it was proceeded to model the hybrid system with all its components in the software Hybrid Optimization Model of Electric Renewable - HOMER, which is commonly used for the modelling of processes and energy systems, especially renewable energy systems.

Results

1.9 Electrical requirements

Figure 2 shows the trend of the kWh consumed by the residence object of study in the period between 2012 and 2016.

Figure 2 Monthly electricity consumption



It was possible to identify that the months with the highest consumption were April (478 kWh) followed by the month of February (476 kWh), January (469 kWh) and July (469 kWh). The months with the lowest consumption were June (430 kWh) and December (428 kWh). The latter could be due to holidays and/or periods of recess that the inhabitants of the residence have in common.

In general, the descriptive analysis showed that the electric power consumption in kWh ranged from 375 kWh (minimum value) to 566 kWh (maximum value), obtaining an average value of 458 kWh.

On the other hand, based on Figure 2 it can be inferred that the rates are not constant. Since 2013, there has been an increase in rates, which becomes more noticeable between 2015 and 2016. It is then that between 2013 and 2014 the rate increased by 6%, between 2014 and 2015 a value of 4%, but between 2015 and 2016 it increased by 10% considering only the annual change, because if it is evaluated between 2013 and 2016 an increase of 25% is presented.

The average monthly rate ranged between a minimum value of $ 0.135 USD/kWh and a maximum value of $ 0.144 USD/ kWh. It also has that the average value in the years studied is 0.139 USD/kWh per month. The costs paid presented an average value of $ 63.69 USD, with a maximum of $ 84.37 USD in the month of July 2014.

1.9.1 Load requirement estimations

Based on the history of the bills and a daily analysis made during a month to the consumption that occurs in the house. It was determined that the average value of the consumption on the day was 15.62 kWh-day considering the peak hours where the highest consumption is generated (Figure 3), which is at 6 am, at noon between 12 and 2 pm, and at night at 6 pm.

Figure 3 Electricity rate History

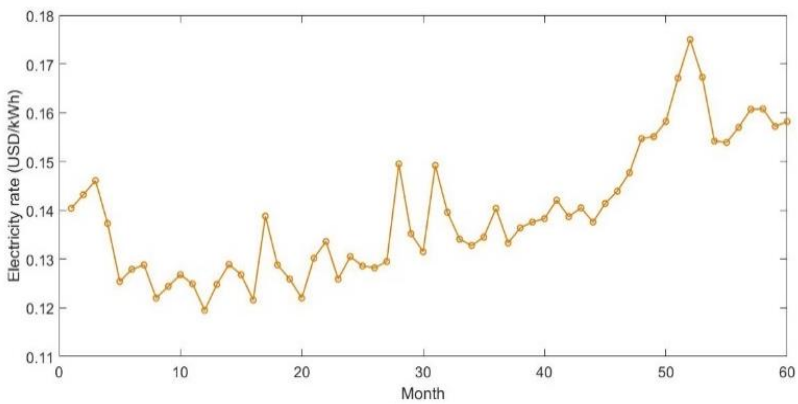
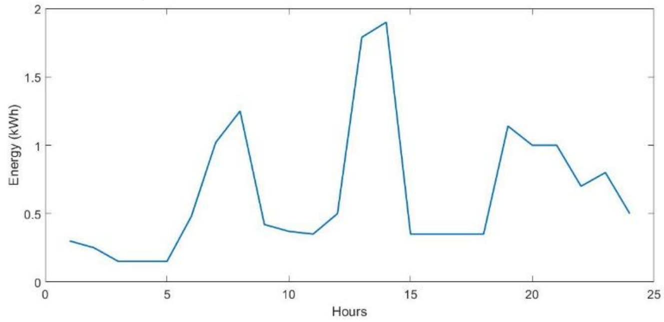


Figure 4 Load profile of the residence

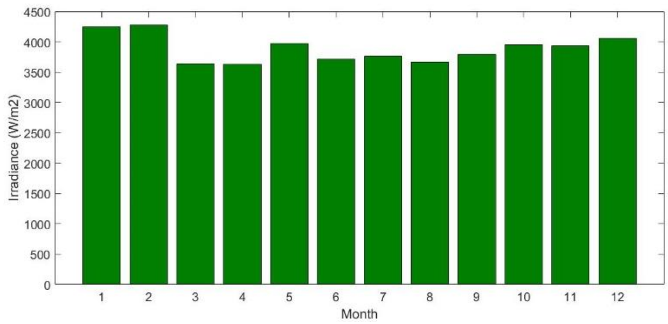


1.10 Solar Potential

The solar radiation was analysed in the nodes obtaining the average values shown in Figure 4. In general, the data indicate a trend with little annual variation. For the Hacienda Manila station, a daily average of 4760 W/m^2 was obtained with a minimum for the month of March of 2014 (3537 W/m^2), while the highest report was evidenced in February 2007 (5810 W/m^2). In the case of the La Plata station, a daily average of 3016 W/m^2 was identified with minimum and maximum values: 843 W/m^2 (March 2008) and 4465 W/m^2 (January 2014).

Figure 5 presents the monthly average of solar radiation values where there is an average of 3888 W/m^2 with a maximum of 4280 W/m^2 and a minimum of 3640 W/m^2.

Figure 5 Solar Irradiance



Daily solar brightness for the same period showed values between 5 and 6 hours of sunshine per day. The maximum was for the month of January 2010 with 8 hours and the minimum in June 2007 with 4 hours.

1.11 Wind Potential

The wind speed is influenced by certain environmental parameters. Some of which were considered in the study were the ambient temperature and precipitation.

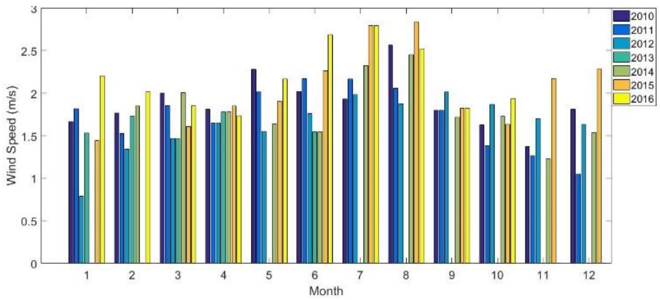
The ambient temperature presented minimums of 20°C and 21°C, maximums between 35°C and 38°C; and means close to 27°C and 29°C, for the period between 2005 and 2016; the data show a behaviour with little variation of the temperature in the period analysed.

The rainfall data for the same period showed that in October 2007 the highest amount of precipitation reached in 474.2 mms, while the lowest was in December 2015 with 0.6 mms. Additionally, in November 2010 the greatest number of days of precipitation was presented with 29 days, while in December 2015 there was only one day.

The monthly average values of wind speed presented in Figure 6 showed a higher wind speed during the month of August 2015, with a value of 2.83 m/s; while its minimum was evidenced in the month of January 2012, with a value of 0.78 m/s.

Carrying out a more detailed analysis for January 2012, month with the minimum wind speeds of the period analysed, shows that the maximum value is presented on day 24 with 2 m/s, while its minimum is on day 9, with a value of 0.07 m/s. According to the data reported by the IDEAM, the direction that was presented more frequently in this month were northbound.

Figure 6 Wind Speed



Similarly, a detailed analysis for August 2015 reveals that the maximum wind speed occurs on day 22 with a value of 4.5 m/s, while its minimum is on day 26 was 1.475 m/s. In addition, following the data reported by the IDEAM, the direction that was presented most frequently in this month were southerly.

1.12 Hybrid system settings

Table 3 presents a summary of the input values that were used in the simulation and design of the hybrid solar-wind system.

Table 3. Hybrid system input values.

Variable	Minimum	Maximum	Mean	Units
Solar Irradiation	2808	5333	3888	W/m^2
Electric consumption	375	566	458	kWh
Mean temperature	26	31.6	28.1	°C
Maximum temperature	33.3	39.2	36.2	°C
Total precipitation	0.6	458.3	116.4	mm/s
Solar shine	4	7.1	5.5	Hours/day
Wind speed	0.78	2.83	1.85	m/s

As defined in Table 3, the design configuration of the hybrid solar energy system (SHES), the results of the calculations of these processes are shown below.

Table 4 shows the details of the components of the hybrid system for settings 1 and 2 corresponding to a daily load distribution of 80/20 and 50/50 respectively for the PV/WP ratio. Setting 1 presents a system of 3.18 kW of installation power while the second a system of 6.12 kW. Additionally, it could be found that the performance for a photovoltaic system according to the module used and the Neiva conditions was 19.69 kWh/kWp and for the wind resource 1.5 kWh/kWp considering a turbine of 800W of power and average winds between 1.85 m/s and 2.39 m/s. It can be observed in the same way that the setting 1 that has the largest number of photovoltaic modules has a higher energy generated.

Because of the solar conditions, the setting 3 that considers a system formed only by photovoltaic modules, presents a greater generation of energy compared to the setting 4 that considers a system only with turbines. Table 6 shows the details of settings 3 and 4, where it is important to highlight 4 photovoltaic modules and 14 wind turbines, which shows a great difference in units that, will later influence a representative difference in cost.

1.13 Hybrid system costs

The costs of the hybrid solar wind system were obtained from information supplied by three national suppliers, one international supplier, considering the availability of shipment to Colombia and the stock. A synthesis of the costs of each component was made and at the end the lowest values were selected.

Table 4 Sizing Settings 1 and 2.

Setting	**1**		**2**		
Technology	PV	WP	PV	WP	Units
Daily load	12,496	3,124	7,81	7,81	kWh-day
Nominal power	260	800	260	800	W
Quantity	3	3	2	7	
Installed power	780	2400	520	5600	W
Performance	19,69	1,5	19,6	1,5	kWh/kWp
Output power	15,36	3,6	10,2	8,4	kWh-day
SHES total power	3,18		6,12		kW
SHES output power	18,96		18,64		kWh-day
Performance	5,96		3,05		kWh/kWp
Batteries					
Voltage single battery	12		12		VDC
Battery capacity	115		115		Ah
Performance battery bank	67455		69230		Wh
batteries connected in series	2		2		
batteries connected in parallel	24		26		
Total batteries	48		52		

Table 5 (Continued): Sizing Settings 1 and 2.

	Hybrid battery charge controller		
Nominal power	3200	10000	W
Maximum power	6000	20000	W
Voltage	24	24	VDC
Efficiency	85	90	%
	Inverter		
Nominal power	3,21	6,18	kW
Input power to inverter	19,45	19,12	kW
Power factor	99	95	%
Inverter efficiency	97.5	95	%
Total inverter power	3300	18000	W

It is important to mention that the inclusion of batteries or not to the hybrid system, determines in large percentage an increase in the total cost of the system, since it represents 47% of the initial cost and more than 100% of the operation and maintenance costs due to the number of spare parts that must be carried out in the 25 years of the project. The batteries are designed to work in cycles of loading and unloading, the greater the number of cycles the shorter the life time. Considering that the battery bank operates every day under normal conditions, it would be speaking of an approximate duration between 5 and 8 years, therefore, the number of changes that must be made in the project period is between 3 and 5 times.

Table 6 Sizing Settings 3 and 4.

Settings	**3**		**4**		
Technology	PV	WP	PV	WP	Units
Daily load	15,62			15,62	kWh-day
Nominal power	260			800	W
Quantity	4			14	
Installed power	1040			11200	W
Performance	19,69			1,5	kWh/kWp
Output power	20,48			16,8	kWh-day
SHES total power	1,04		11,2		
SHES output power	20,48		16,8		
Performance	19,69		1,5		
		Batteries			
Voltage single battery	12		12		VDC
Battery capacity	115		115		Ah
Performance battery bank	73076		67317		Wh

Table 7 (Continued): Sizing Settings 3 and 4.

batteries connected in series	**2**	**2**	
batteries connected in parallel	27	24	
Total batteries	54	48	
Hybrid battery charge controller			
Nominal power	1000	15000	W
Maximum power	1040	18000	W
Voltage	24	24	VDC
Efficiency	98	99,6	%
Inverter			
Nominal power	1,0	11,2	kW
Input power to inverter	22,76	17,2	kW
Power factor	97,5	95	%
Inverter efficiency	90	97,7	%
Total inverter power	2,0	13,8	W

The setting 1, Table 8, shows the detail of the costs of a hybrid solar wind system for the useful lifetime. This includes a storage system with batteries, being $ 130 USD, the cost of a 115 Ah battery. To supply the daily demand with an autonomy of 3 days, a percentage of depth of discharge in 75% and an efficiency of 95%, 48 units are required, representing $ 6,240 USD, compared to the initial cost of $ 13,264 USD.

Operation and maintenance costs $3,685.3 USD, include minor repairs and items related to the change of the investor and controller that estimates a change in the project period. Both have a lifespan between 10 and 15 years. Additionally, this item does not include the change of the battery bank, between 3 and 5 times, that is to say $ 31,200 USD, which represents approximately 2 times the initial cost of the project, which raises the budget required for its maintenance.

For this reason, it came to the point of considering a system connected to the grid, without including storage, that is, using the internal electrical grid of the residence and not storing the surplus energy of those days with higher production. In addition, since the main function of the charge controller or controller is directly related to the operation of the batteries, this cost will not be included in the analysis either.

In the same way, Figure 4, the load profile of the residence, supports assertiveness in the type of connection of the defined system, because the requirement between 6:00 a.m. and 06:00 p.m. is 10.14 kWh, 65% of the daily total (15.62 kWh), leaving only 35% of electricity (5.48 kWh) to supply overnight conventional energy.

Table 8 presents the items for settings 1 and 2 of the solar wind hybrid system without storage system, i.e. without batteries, for the entire estimated period of system operation.

Table 8 Batteries costs, setting 1.

Component / System	Unit Cost	Setting 1	
		Quantity	Cost
PV module 260W	287	3	861
Wind turbine 800W	759	3	2277
Batteries	130	48	6240
Battery charge controller			624
Inverter			1200
		Total components	11202
		Other components	1120
		Installation	941,4
		Operation and maintenance	3685,3
		Dismantling	156,9
		Lifetime Final cost	17106

Table 9 Costs Setting 1 and 2.

Component / System	Unit Cost	Setting 1		Setting 2	
		Quantity	Cost	Quantity	Cost
PV module 260W	287	3	861	2	574
Wind turbine 800W	759	3	2277	7	5313
Inverter			1200		1549
		Total components	4338		7436
		Other components	434		744
		Installation	941,4		1766,1
		Operation and maintenance	1587,4		711,6
		Dismantling	156,9		294,35
		Lifetime Final cost	7457		10952

Setting 1, 80% photovoltaic source and 20% wind source, has an initial cost of $ 5,713 USD which includes:

- The hard cost components: 260W photovoltaic modules, wind turbines, hybrid inverter;
- The Soft costs: associated with the installation as associated civil works, transportation of components and materials.
- Costs of other minor components such as cable, protection system and security against electrical risk.

The final cost of the system's useful life for this setting was $ 7,457 USD, taking into consideration the costs related to minor maintenance and the investor's change.

If you consider that a photovoltaic module represents 38% of the cost of a wind turbine, it is expected that by increasing the number of turbines in a setting such as the case of number 2, there is an increase in the cost of the components in the beginning, as well as in the minor repairs.

For its part, setting 2, 50% photovoltaic source and 50% wind source, has an initial cost of $ 9,946 USD, which contains 7 turbines and 2 photovoltaic modules, for a final cost of $ 10,952 USD.

However, when considering a setting 3 with only photovoltaic modules, 4 units, it has an initial cost of $ 1,772 USD and a total cost of $ 1,956 USD. On the other hand, a system based 100% on wind power has an initial cost of $ 19,069 USD which includes the use of 14 turbines of 800W to supply the energy demand, obtaining a final cost of $ 20,964 USD. The detail can be seen in Table 10.

Another aspect to consider is the cost of dismantling all the equipment at the end of the project's life cycle, for which the considerations presented in [13] were applied for all configurations.

Table 10 Costs settings 3 and 4.

Component / System	Unit Cost	Setting 3		Setting 4	
		Quantity	Cost	Quantity	Cost
PV module 260W	287	4	1148		
Wind turbine 800W	759			14	10626
Inverter			150		3811
		Total components	1298		14437
		Other components	130		1444
		Installation	344,4		3187,8
		Operation and maintenance	126,8		1364,3
		Dismantling	57,4		531,3
		Lifetime Final cost	1956		20964

1.14 Financial Evaluation

The first parameter that must be determined in the financial evaluation of a renewable energy system and energetic in general, is the levelized cost of energy (LCE), which means the equivalent cost per kWh evaluated in the energetic project period.

The Table 11 shows the relation of the LCE for each one of the configurations of the residential solar wind hybrid system with internal connection to the selected grid of the proposed ones. In addition, setting 3 (100% photovoltaic) estimates the lowest LCE cost at 0.26 USD/kWh while the setting 4 (100% wind) the highest at 3.42 USD/kWh. In the same sense, the annual generated energy by the system is higher in Setting 3 and lower in setting 4.

Table 11 Levelized Cost of Energy (LCE)

Setting	Cost USD	Daily Energy kWh	Annual Energy kWh	LCE ($/kWh)
1	7457	18,96	6920,4	1,08
2	10952	18,64	6803,6	1,61
3	1956	20,48	7475,2	0,26
4	20964	16,8	6132	3,42

Table 12 presents the ALLC for the proposed configurations. These allow to identify that setting 3 has the lowest value of $ USD/year in 108.61 and setting 4 the highest (10 times).

Table 12 Annual Life Cycle Cost

Setting	Cost USD	Annual Energy kWh	ALCC ($/year)
1	7457	6920,4	414,05
2	10952	6803,6	608,11
3	1956	7475,2	108,61
4	20964	6132	1164,03

The next step with LCE or ALCC values is to evaluate the net present value NPV, which corresponds to the total cost of the project in the future. Table 13 shows the values for the proposed options and highlights the setting 3 as the one with the lowest cost in the future.

Table 13 Net Present Value

Setting	Total Cost	Initial Cost	Net Present Value (NPV)
1	7457	5713	9733,4
2	10952	9946	12059,8
3	1956	1772	2159,1
4	20964	19069	23047,3

Another important factor to consider in this section is the economic benefit that the State grants to those who invest in projects that involve the use of renewable energy technologies. According to the law 1715 of May 3, 2014, those who invest in unconventional sources of energy will be able to access to a series of tax incentives, the most outstanding is the exception of the payment of VAT and the reduction of the declaration of income up to 50 %. Being the latest one interest and predominant to those taxpayers who must pay their taxes by income statement, due to, according to the tax reform of the law 1819 from December 29, 2016 that started into rigor from January 1, 2017, all-natural people or legal entities that own real property by proper noun that exceed $ 47,572 USD must pay taxes for this concept.

In view of the foregoing, considering that the objective residence of the project design exceeds the stipulated value, that is, that the owner must pay taxes to the State for exceeding these values, it is pertinent to propose a scenario where the second benefit is included in the economic evaluation of the project, since it presents indirectly a saving to the owner of the real property.

Table 14 shows the detail of the calculations that consider the tax benefit of the discount of 50% of the initial investment, can be detailed in the column headed "Desc 1715 Law" as well as the new final total cost of each of the proposed configurations. On the other hand, Table 15 shows the new calculation of the LCE with the new defined costs. It shows that configuration 3 continues taking the lowest value followed by setting 1.

Table 14 Costs with Tax Incentives 1715 Law

Setting	Total Cost USD	Initial Cost	Desc 1715 Law	New Final Cost
1	7457	5713	2856,5	4600,5
2	10952	9946	4973	5979
3	1956	1772	886	1070
4	20964	19069	9534,5	11429,5

Table 15 New levelized energy cost (LCE)

Setting	New LCE ($/kWh)
1	0,66
2	0,88
3	0,14
4	1,86

Finally, Table 16 presents the cost of kW installed in USD for the four proposed options. Setting 4 stands out because it has the lowest value at $1702.6 USD/kWp followed by configuration 3 with $1703.8 USD/kWp. It is possible to note that the low cost of the kW installed in Setting 4 is justified because it is the option that has the greatest power and because in this case it obeys to the supply and demand law, the greater the quantity, the lower the Price.

Table 16 kW installed Cost

Setting	Power (kWp)	Initial Cost	Annual Power kWh	$/kWp
1	3,18	5713	6920,4	1796,5
2	6,12	9946	6803,6	1625,2
3	1,04	1772	7475,2	1703,8
4	11,2	19069	6132	1702,6

1.14.1 Payback Period

The PBP is an important indicator of the feasibility assessment in most of the investment projects. For energy projects with a very high PBP higher than 8 years, the investment could become unviable [21]–[23].

Table 17 and Table 18 show the PBP for the 4 proposed options of photovoltaic solar wind hybrid systems, highlighting that the second table includes the values with the application of a part of the tax incentives that the law 1715 offers. In the first scenario, without benefits, only option 3 with photovoltaic modules shows an acceptable value PBP in 1.9 year; while including the benefits options 1 and 3 could show viability.

Table 17 Payback period

Setting	Total Cost (P)	Annual Power kWh	Saving per Generated energy in 1 year (USD)	PBP
1	7457	6920,4	967	7,7
2	10952	6803,6	950	11,5
3	1956	7475,2	1044	1,9
4	20964	6132	856	24,5

Table 18 PBP with Law 1715 Benefits

Setting	Total Cost (P)	Annual Power kWh	Saving per Generated energy in 1 year (USD)	PBP
1	4600	6920	967	4,8
2	5979	6803	950	6,3
3	1070	7475	1044	1,0
4	11429	6132	856	13,3

The saving-investment ratio, Table 19 shows that in common all the values are higher than 1, which is the expected positive behaviour, due to one of the aims of a renewable energy system is the search for economic savings and this value represents this trend. Option 3 stands out for having a high SIR.

Table 19 Savings and investment ratio (SIR)

Setting	Total Cost	Saving per generated energy in 25 years	SIR
1	7457	24.164	3,2
2	10952	23.756	2,2
3	1956	26.101	13,3
4	20964	21.411	1,0

1.15 Reliability analysis

1.15.1 LPSP analysis

The calculations for the 4 proposed configurations show that the systems, despite the variations of the wind and solar resource during the year, fulfil with the energy supply, since it presents values between 0 and 0.25, highlighting that the setting 3 presented the lower value.

1.16 Optimization and sensitivity cases

Thanks to the versatilities that HOMER presents, variations of energy sources in the different sensitivity scenarios, only 3 cases were considered. The first where the settings 1 and 2 are evaluated, the second for setting 4 and the third for setting 3.

1.16.1 Case 1: Settings 1 and 2.

In this scenario, the hybrid combinations between the wind and solar resource are considered, in addition the contribution of the grid and a diesel generator are considered. Some of the initial economic conditions are a real discount rate of 2.74%, inflation rate of 3.17%, project life 25 years and an initial capital cost of $ 4338 USD.

The simulation was carried out by finding 86,322 solutions of which 86,313 were omitted due to financial infeasibility or minimum renewable fraction. The basic simulation scheme in Figure 7 shows the components included in the calculations made.

Figure 7 HOMER Diagram for Setting 1

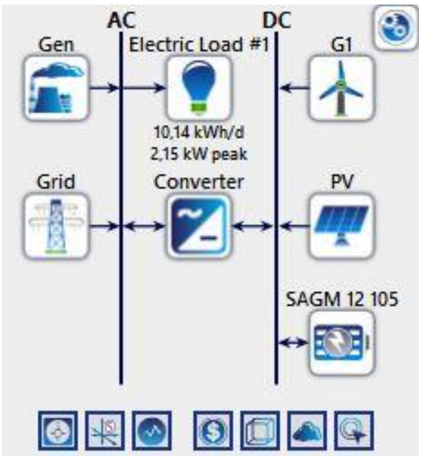


Table 20 HOMER Simulation. Setting 1

Wind Scaled Aver (m/s)	COE (USD)	NPC (USD)	Ren Fracc (%)	CO_2 (kg/yr)
1,85	$0,190	$12.588	50	1.170
3,0	$0,190	$12.588	50	1.170
8,0	$0,179	$11.878	62,3	881
1,85	$0,190	$12.588	50	1.170
3,0	$0,190	$12.588	50	1.170
8,0	$0,179	$11.878	62,3	881
1,85	$0,190	$12.588	50	1.170
3,0	$0,190	$12.588	50	1.170
8,0	$0,179	$11.878	62,3	881

Table 20 shows the 9 solutions selected for having the lowest cost of energy COE and the largest fraction of renewable sources, presents combinations that include random groups among turbines, photovoltaic modules, batteries, grid connection and diesel generator. Although the latest was excluded from the selection. There are 3 combinations with a lower COE of \$ 0.179 USD / kWh, a NPC of \$ 11,878 USD and a renewable fraction of 62.3%.

It can be observed that the CO_2 produced by the same solution in 881 Kg/yr as well as inverse trends between the COE, NPC and the renewable fraction, because as the fraction decreases, the other two variables increase. On the other hand, if it is analyse the wind speed average scale considered for each case, we can deduce that it is proportional to the renewable fraction and for the solution presented and it has a value of 8 m/s, a value that according to the analysis of the Wind energy resource does not occur in Neiva since the average is 1.85 m/s and in the months with the highest speed it is 2.85 m/s. Which makes the solution 1 is the closest to the proposed configuration where the COE is at \$ 0.190 USD/kWh, NPC at \$ 12.588 USD and a renewable fraction of 50%.

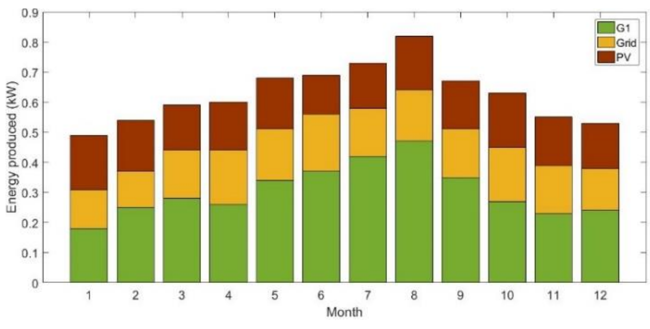
It is possible to have a detail for the simulated costs differentiated by components in Table 21 where, "Generic 1kW" alludes to the wind generator with the turbine, it is observed that it says 1kW, but the characteristics that it has in consideration are the equivalent to the turbine of 800W. Another aspect that can be deduced is the cost of the turbine, which is approximately twice the cost of the module over the life of the project. The initial cost is estimated at \$ 6,078 USD and a final cost of \$ 8,403 USD for the entire period excluding the costs that are presented as "Grid", it means, the network contribution.

Table 21 Synthesis cost. Setting 1

Component	Capital (USD)	Replacement (USD)	O&M (USD)	Total (USD)
Generic 1kW	759	0,00	978,06	$1.737
Flat plate PV	703	0,00	57,87	$760
Grid	0,00	0,00	3474,4	$3474
Other	4338	0,00	1138	$5476
Converter	278,42	185,53	12,81	$429,5
System	6078	185,53	661,19	$11.877

The hybrid system, as shown in Figure 8, has the capacity to produce between 0.5 kW and 0.8 kW of power, the higher peak in the month of July. In addition, it is possible to differentiate the contribution of each source of energy where wind is higher, followed by that of the grid and the solar one.

Figure 8 Energy produced. Configuration 1



Related to the financial evaluation, Table 22 presents some variables of interest, which highlights a payback period in 7.21 years, and a payback rate of 9.6%.

Table 22 HOMER financial evaluation

Metric	Value
Present worth ($)	894
Annual worth ($/yr)	50
Return on investment (%)	9,6
Internal rate of return (%)	12,6
Simple payback (yr)	7,21
Discounted (yr)	8,74

Greenhouse gas emissions estimated to be generated by the system include the emission of carbon dioxide 881 kg/yr, sulphur dioxide 3.82 kg/yr and nitrogen oxides 1.87 kg/yr (Table 23).

Table 23 GHG HOMER evaluation

Quantity	Value	Units
Carbon Dioxide	881	Kg/yr
Carbon Monoxide	0	Kg/yr
Unburned Hydrocarbons	0	Kg/yr
Particulate Matter	0	Kg/yr
Sulphur Dioxide	3,82	Kg/yr
Nitrogen Oxides	1,87	Kg/yr

1.16.2 Case 2: Setting 4.

Table 24 presents 9 solutions for architecture with only one renewable energy source. The sensitivity parameter is the average wind speed, which in the first column has a variation from 3 to 12 m/s. The lowest COE is obtained when the speed is 3 m/s, the NPC $ 140,619 USD and the fraction renewable at 50%.

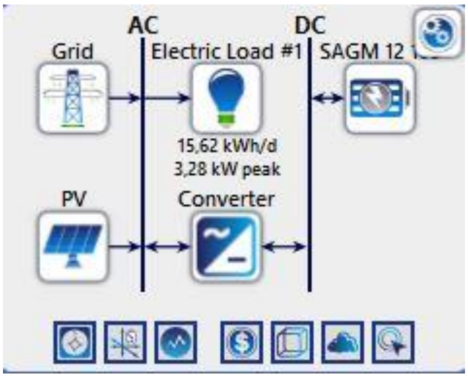
Table 24 Simulation HOMER. Setting 4

Wind Scaled Aver (m/s)	COE (USD)	NPC (USD)	Ren Fracc (%)	Energy kWh/yr
12	$1,40	89.038	50	3.339
3	$0,881	140.619	50	3.339
6	$1,03	115.029	50	3.339
12	$1,40	89.038	50	3.339
3	$0,881	140.619	50	3.339
6	$1,03	115.029	50	3.339
12	$1,40	89.038	50	3.339
3	$0,881	140.619	50	3.339
6	$1,03	115.029	50	3.339

1.16.3 Case 3: Setting 3.

Finally, the results of the scenario are presented where only is considered an energy system based on solar supply by means of photovoltaic modules. Figure 9 shows the components of this model: PV, Grid, SAGM 12 (batteries) and converter (inverter).

Figure 9 HOMER Diagram for Setting 3



4668 simulations were made of which only 9 presented one greater than 50% renewable fraction. The parameter for cases of sensitivity was the nominal discount rate, because while he was one of the initial values entered, the software used it to obtain the solutions presented in Table 25. These are arranged in descending order, where the last COE value of $0,0515 USD/kWh represents the best solution for being the lowest cost of energy. In addition to this, has minor NPC in $8.537 USD and a renewable fraction of 65.2%, the highest. The energy produced per year is 6.207 kWh to 3,309 kWh purchased the electric company to supply the consumption during the hours of the night for a year. Two cases of optimization in Table 26, presented correspondence with this trend, one without considering the incorporation of batteries.

Table 25 Simulation HOMER. Setting 3

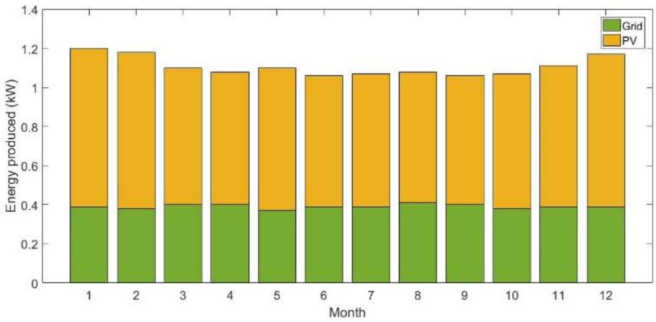
Nominal Discount (%)	COE (USD)	NPC (USD)	Ren Fracc (%)	Energy kWh/yr
12	0,135	7.874	50	3.716
12	0,135	7.874	50	3.716
12	0,135	7.874	50	3.716
6	0,0738	8.421	62	5.537
6	0,0738	8.421	62	5.537
6	0,0738	8.421	62	5.537
3	0,0515	8.537	65,2	6.207
3	0,0515	8.537	65,2	6.207
3	0,0515	8.537	65,2	6.207

Table 26 Optimization HOMER. Setting 3

Nominal Discount (%)	COE (USD)	NPC (USD)	Ren Fracc (%)	Energy kWh/yr)
3	0,0515	8.537	65,2	6.207
3	0,0530	8.781	65,2	6.209

The electricity produced per year is listed by source in Figure 10, where the greatest contribution is from photovoltaic source 0.8 kW followed the night the network supply approximate 0.4 kW.

Figure 10 Energy produced Setting 3.



The financial assessment by the HOMER in Table 27, presented a return on investment at 10.71 years with a rate of return of 5.3%. Participation for the photovoltaic array was 65.2% and 34.8% for the network.

These results were simulated whereas 4.38 hours of operation of the modules and a COE of $ 0.07/kWh and an annual production of 6.207 kWh/yr.

Table 27 Financial evaluation HOMER Setting 3.

Metric	Value
Present worth ($)	1.185
Annual worth ($/yr)	68
Return on investment (%)	5,3
Internal rate of return (%)	8,0
Simple payback (yr)	10,71
Discounted (yr)	13,11

GHG emissions were presented in the environmental component: 2091 kg/yr, sulphur dioxide carbon dioxide 9.07 kg/yr and nitrogen oxides 4.43 kg/yr presented in Table 28.

Table 28 GHG HOMER Setting 3.

Quantity	Value	Units
Carbon Dioxide	2091	Kg/yr
Carbon Monoxide	0	Kg/yr
Unburned Hydrocarbons	0	Kg/yr
Particulate Matter	0	Kg/yr
Sulphur Dioxide	9,07	Kg/yr
Nitrogen Oxides	4,43	Kg/yr

Results analysis and discussion

Stands a daily average radiation of 3.8 kW/m^2 with maxima near 5.3 kW/m^2, proving the viability of the potential solar while presenting an unfavourable atmosphere with an average of 1.85 m/s with maximum wind speed for wind resource close to 2.83 m/s presented frequently in the days of the month of August of the period studied. It is considered negative because the minimum speed required to have any conventional turbine start to turn is at 3 m/s, which makes that he arises a first statement about the technical infeasibility of a stand-alone wind power system.

There are some turbines designed by ICEWIND for extreme conditions where they consider minimum wind speed of 2 m/s. That case was not considered in the evaluation because of unavailable any kind of technical information to perform the exercise.

The power consumption of the node's study showed values between 375 and 566 with an average of 458 kWh kWh. At this point the profile load and a daily energy requirement identified consumption of 15.62 kWh-day for a monthly total of 468 kWh.

Knowing the panorama of renewable energy sources: Sun and wind; as well as the hypothesis of the wind resource was determined important to define 4 configurations of hybrid systems with the addition of an option for 100% PV and the other to 100% wind energy.

Up now it had been considered standalone settings, i.e. isolated from conventional electrical network, but due to the high amount of batteries requiring every architectural design, between 48 and 54 units without considering the replacement. According the costs related to the life cycle of batteries which means a minimal change of 3 times the amount mentioned. It was decided to opt for a system connected to grid providing a 65% of energy supply for electrical demand during the hours of the day.

For configuration 1, System hybrid without replacement batteries had a cost of $17.106 USD compared with $7.457 USD for Setup with connection to the grid, a savings of 44% with respect to the first cost. For other configurations, the cost can be seen in Table 29.

Moreover, technical feasibility is presented for settings 3 and 1 as they are those that have lower costs and greater annual energy produced, if not evidenced when the fraction of wind resource, WP is increased.

Table 29 Settings and costs.

Settings	Fraction (PV /WP)	Cost USD	Daily Energy kWh	Annual Energy kWh
1	0,8 / 0,2	7457	18,96	6920,4
2	0,5 / 0,5	10952	18,64	6803,6
3	1,0 / 0	1956	20,48	7475,2
4	0 / 1,0	20964	16,8	6132

The financial evaluation, a sensitive but crucial topic at the time of an investment of large sums of money was done by independent and correlated analysis of the following economic parameters: the Levelized Cost of Energy LCE/COE, the

Annual Life Cycle Cost - ALCC, the net present value NPV, the payback period - PBP, saving and investment – SIR and installed kW, within the most representative patterns.

The setting 3 presented the best solution with a favourable for implementing economic scenario, as it had the lowest LCE in 0.26 $USD/kWh, an allocation in 108,61 $USD/year and a future cost of $2.159,1 USD. The option with 100% wind showed the reverse behaviour with high values. The lower cost of installed kW was setting 4 as this presented the greatest power installed in 11.2 kW (wind turbines).

Having into account the tax incentives of Law 1715 as a reduction of income taxes for the owner of the system and the residence. They presented a reduction of 50% of the initial cost and an additional 5% on the total cost of the project. The new estimated cost of energy was 0.14 $USD/kWh for PV setting and 1.86 $USD/kWh for wind power.

Additionally, the lower PBP was 1.9 years for the photovoltaic array and a pretty good SIR in 13.3 which makes this configuration considered most appropriate for the study area.

Conclusions

Weather conditions in the city of Neiva have favourable for harnessing energy from solar resource as alternates to the hydroelectric plant. In contrast, the wind resource is not suitable for use since there is wind speeds high and consistent to consider their use and inclusion in the energy matrix of the Neiva area.

Architecture hybrid optima found, although it does not correspond to source 100% renewable, includes photovoltaic&solar resource and connection to grid to supply the energy consumption with a distribution 65% and 35% respectively.

A System consideration of storage batteries in any configuration of hybrid systems showed a non-viability of the residential projects due to the number of spare parts because of the short time of life.

The inclusion of tax benefits reflects a relative advantage of a solar system against the hydroelectric power as that present in 0,0515 $USD/kWh energy cost values below the average cost of the energetic company in 0,139 $USD/kWh, excluding the rate of annual increase that presented between 6% and 7%.

Due to the higher electrical consumption occurs between 6 am and 6 pm, allowed that the load profile was favourable for the technical and economic calculations.

The results of optimization software HOMER proved to be very relevant to the exercise because they provided solid tools for financial and environmental assessment of the proposed settings.

Future scope

The evaluation system of hybrid wind-solar performed identifies its infeasibility in Neiva due to low wind speed presenting, but the behaviour of the wind resource in the Department of Huila does not address what might be considered as a subject of study for further research.

The load profile analysed in the study was that corresponding to the residential area. Further studies could evaluate systems for the industrial zone of the city of Neiva considering that most of the buildings in this area are its high-power consumption during the hours of sunshine.

For the economic and financial evaluation were presented in a superficial manner one of the benefits of the 1715 law for the promotion of renewable energy projects but does not consider the impact of including all the benefits provided by the State standard. An analysis of economic feasibility including all the deductions that can be applied, could be considered as a target for a later work.

The energy matrix of the Department can be expanded by incorporating the participation of non-conventional sources of energy. The region has other resources such as groundwater, regions with agricultural and forest biomass, biogas, geothermal reservoirs, municipal solid waste and some natural water currents. They could both be considered to evaluate its potential in the region as to the determination of the best configuration for an independent energy system or hybrid to provide energy consumption of some population.

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