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Technical-Economic Analysis of the Implementation of a Microgrid with Integration of Renewable Energies in the Esmeraldas Canton, Ecuador

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Keywords

distributed generation; renewable energies; implementation; microgrid; technical-economic;

Abstract

The integration of renewable energy technologies and the consequent reduction in investment costs has led to an increase in the use of distributed energy resources (DER), which has allowed the deployment of more and more microgrids. Despite the many benefits that can be derived from microgrids, they still face many barriers to participating in the electricity industry compared to traditional grids. This paper proposes to address the implications of installing renewable energy in the parish 5 de Agosto, Stone Mine Sector of the city of Esmeraldas, through a technical-economic analysis of the implementation of a microgrid using the HOMER network software. The analysis shows that implementing a microgrid for renewable energy production significantly reduces total costs, unit energy costs and carbon dioxide emissions over the entire project life cycle. Finally, it is concluded that the photovoltaic matrix produces 82.3%, wind turbines 15.3% and the contribution from the grid is 2.45% of the total energy, respectively. The percentage of renewable energies in the system is 100%.

Contents

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1 Introduction

Energy has become one of the pillars that support the development of today's society, so its availability and good use are already a key piece in determining the success or failure of world economies. Much to the chagrin of the Western world, the years of cheap and seemingly infinite energy that occurred for much of the twentieth century are definitely behind us. The new twenty-first century has given way to an era in which the proven reserves of oil and natural gas have stopped increasing year by year and the horizon of 2050 for the first of these products and 2075 for the second, is already seen as a real possibility for the total depletion of this type of resources. Given this circumstance, in the development of the content the reader will be able to visualize major axes in which the actions in energy matters in relation to Distributed Generation for the coming years must be framed, these being the following: a) Adapt the offer of energy products to the coverage of needs, improving the reliability of the electricity supply, gas and hydrocarbons; (b) Promoting energy generated from renewable and environmentally friendly sources by doubling its contribution to the regional energy balance; c) Improve the efficiency of use of energy products, promoting savings in their use through the proposal of measures, both horizontal and of direct sectoral impact, reducing energy consumption in the year; and d) Minimize the environmental impact of our energy consumption, contributing to the reduction of energy CO2 emissions, reducing emissions from energy consumption in the year. Countries in the region and the world have produced a significant increase in the number of GD installations. With this, new requirements have arisen in the Distribution Systems: the increase or reduction of losses, the need to strengthen the capacity of lines and substations (transformation centers) to give space to the new power flows injected by the GD or vice versa, it could be necessary to reduce the volume of investments in repowering the networks (generating at points close to demand reduces energy flows). The connection of these generators at the lowest levels of the hierarchical scheme alters this scheme, posing a series of problems of a technical and regulatory nature (Lopes et al., 2007; Ackermann et al., 2001).

In the case of Ecuador, GD is considered in the energy planning of this country and in this sense the provision of energy is guaranteed in the constitution, giving way to the creation of a regulatory framework that favors the establishment of policies that guarantee sustainability in energy matters, which is why the importance of work. GD can serve many purposes, but the most important are energy self-sufficiency and selling power to the grid as any other generator would, this is rapidly gaining acceptance in Latin America, and several countries are adopting new regulations to allow small generators to connect directly to the distribution grid and sell their surplus energy to the grid. In countries where GD was already allowed in some form, regulators are looking to improve the framework to stimulate growth in a sector that increases renewable capacity with an extremely low environmental impact, such as the Dominican Republic, Peru, Panama and Colombia (Dincer, 2000; Akella et al., 2009).

The current regulations in most Latin American countries and particularly in Ecuador do not have the maturity and above all the legal, technical and economic elements that incorporate tariffs and measures that allow access with preferential costs or eventually have rules for the free use of networks for the injection of new generation. Even in countries that have carried out previous studies, there are no uniform criteria for the interconnection of GD, it is a model that requires a lot of openness in the negotiation of the parties so that the benefits are achieved in both directions. During this work, we seek to establish the possible adverse effects encountered by GD and identify the challenges to be overcome and obstacles of regulation for the adoption of the configuration of the distribution network.

In this context of distributed generation and microgrid, this article proposes to carry out a technical-economic analysis of the installation of renewable generation sources, such as photovoltaics, combined with storage, integrated into a low voltage network. These sources would serve as an alternative for energy consumption, foreseeing a reduction in costs with the payment of the electricity rate in an electrical installation of the Parish 5 de Agosto Sector Mina de Piedra in the city of Esmeraldas. For this, a simulation will be carried out using the Hybrid Optimization Model of Electric Renewable Energies (HOMER Grid), which will detail the most appropriate configuration to assemble to achieve the best alternative.

Microgrid - concept, features and purpose

There are several contributions in the literature that define the concept of microgrids. Authors such as Karystinos et al. (2022), mention that in a microgrid is a possible example of a future energy system consisting of small types of modules (microturbines, fuel cells, solar systems, etc.) that control identifiable loads. These systems can be networked together or operate in isolation when disconnected from the network. Figure 1 shows some energy sources such as wind power, energy storage, bioenergy, microturbines, photovoltaics and fuel cells that form a microgrid connected to the grid through a common connection point (CCP).

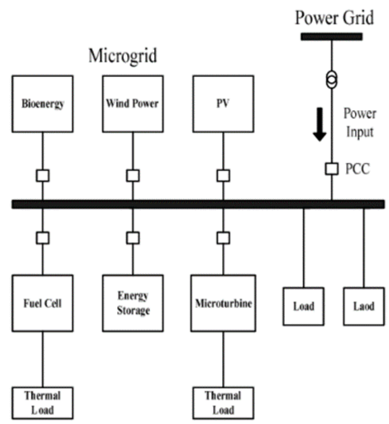


Figure 1. Basic structure of a microgrid

In recent years, problems such as environmental pollution and air quality, which are closely related to the extensive use of fossil fuels, have become increasingly relevant (Gandhi & Gupta, 2021). Therefore, to proactively address these challenges, steps must be taken to diversify the energy matrix and transform it into one with lower emissions. The diversification of the energy matrix refers to the installation of less polluting and highly energy-efficient distributed energy resources (DER). Compared to centralized power generation, it reduces the cost of using and operating transmission and distribution infrastructure. in addition to reducing losses in the transmission line (Gandhi & Gupta, 2021).

The application of new technologies, mainly the development of power electronics interfaces and modern control theory, has highlighted the concept of microgrids. A microgrid is small-scale, independent and decentralized, uses advanced energy technologies, including gas turbines, wind power, solar power, fuel cells, energy storage devices, etc., and is close to users. For large grids, a microgrid can be considered a controllable power supply unit that can operate in seconds to meet the needs of the external transmission and distribution network (Gandhi & Gupta, 2021). Table 1 summarizes the characteristics of the different DERs, their advantages and disadvantages. According to the aforementioned characteristics and the arrangement shown in Figure 1, it can be concluded that the microgrid, due to its flexibility and resource allocation, can guarantee the supply of energy to important loads when the grid is not available.

Table 1
Comparison between distributed energy resources

N°	Technology	Energy matrix	Output Type	Advantages	Disadvantages
1	Engines	Diesel or gasoline	CA	Low cost. High efficiency. Ability to use multiple inputs.	Emission of greenhouse gases.
2	Gas turbine	Diesel or gasoline	CA	High efficiency using CHP. Ecologically correct. Good cost-benefit ratio	High power for small consumers
3	Wind	Wind	CA	Uninterrupted generation.	Still at a high cost.

				Technology developed from renewable sources.	Storage required.
4	Geological thermal	Hot water	CA	Excellent environmental relationship. Low operating cost.	Too big for small consumers.
5	Photovoltaic system	Sun	CC	Emission-free. Useful for various applications.	High installation cost. Storage required.
6	Small hydroelectric generation	Water	CA	Good economic and ecological relationship. Low relative future cost and maintenance. Useful for times of peak demand and excess energy.	Requires appropriate characteristics of the installation region. Difficult expansion.

After connecting to the Internet, the use of energy is further improved, as it eliminates the transmission and distribution of electricity, improves the quality of power and the reliability of the energy system, and acts as an alternative solution to energy supply problems in remote regions, which relate to society in these areas for further economic development. In a microgrid, maintaining a balance between electricity supply and demand is critical for stability, as generation from intermittent sources, such as solar panels and wind turbines, is difficult to predict and can vary widely depending on source availability. (Solar radiation and wind energy resources). The problem of balancing supply and demand becomes even more important when the microgrid operates in autonomous mode, where only limited supply is available to balance demand (Fele, 2017).

2 Materials and Methods

The objective of this section is to provide information on the production of energy from renewable sources and the integration of storage systems for grid connection. The analysis was performed using the HOMER Grid software, taking into account some technical-economic measures. The technical-economic evaluation of electrical systems can be performed using commercial simulation tools, which offer alternatives to complex methods such as complex algorithms and lengthy physical experiments, which are expensive. Currently, several software is available to design, optimize and model renewable energy systems (REA), mainly for technical and economic evaluation (Maskin & Sjöström, 2002; Lieder & Rashid, 2016).

Economic indicators

The two main economic elements, which are the current total network cost (NPC) and the levelized cost of energy (COE), depend on the total annualized cost of the system. Because of this, the user needs to calculate annualized system costs, which correspond to the annual cost of components minus any miscellaneous costs (Hafez & Bhattacharya, 2012). To calculate the total net current cost, the following equation is used:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,N)} \quad (1)$$

Where:
Cann,tot is the total annual cost,
i is the real interest rate year (discount rate),
N the number of years,
CRF (i, N) the capital recovery factor, calculated according to Equation (2).

$$CRF\ (i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (2)$$

In addition, the actual annual interest rate can be determined as follows:

$$i = \frac{i' - f}{1 + f} \tag{3}$$

Where:
f is the inflation rate,
i′ is the nominal interest rate and
i represents the annual real interest rate.

Another variable considered is the levelized cost of energy calculated through Equation 4.

HOMER Grid defines levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, such software divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electrical load served, using the following equation:

$$COE = \frac{C_{ann,tot}}{E_{prim} + E_{def} + E_{grid,sales}} \tag{4}$$

Where:
Eprim → The electrical energy that the microgrid supplies to the essential loads,
Edef →The electrical energy that the microgrid supplies to non-essential loads and
Egrid→Salts the amount of electrical energy sold to the grid.

In the levelized cost of energy equation (5), the total annualized cost is divided by the electrical load the microgrid serves. In the cost-leveled energy equation, the amount of electricity sold to the grid by the microgrid is added. In HOMER Grid, total net current cost is the economically preferable element and has been used in the optimization process, not the levelized cost of energy (Farret & Simoes, 2006). Return on investment (ROI) is the annual cost savings over the initial investment. HOMER Grid calculates the return on investment with the following equation:

$$\mathrm{ROI} = \frac{\sum_{j=0}^{N}(C_{j.ref} - C_j)}{N(C_{eap} - C_{eap,ref})} \tag{5}$$

ROI is the average annual difference in nominal cash flows over the life of the project divided by the difference in the capital cost of the chosen system and base systems. The internal rate of return (IRR) is the discount rate at which the base case and the current system have the same net current cost. HOMER Grid calculates IRR by determining the discount rate that makes the present value of the difference of the two cash flows equal to zero.

$$\sum_{J=1}^{N} \frac{C_j}{(1 + TIR)^N} \tag{6}$$

Another consideration that must be made about the suitability of the project, is the verification of the payback which is the number of years in which the accumulated cash flow of the difference between the current system and the base case changes from negative to positive. Recovery is an indication of how long it would take to recover the difference in investment costs between the current system and the base case system (Shuai et al., 2016; Su & Wang, 2012).

Proposed configuration

The power supply options available in the hybrid microgrid of the system design under consideration are solar photovoltaics, wind power and grid. In characteristics and costs of the components of the system are presented in the following. Figure 2 shows the desired configuration.

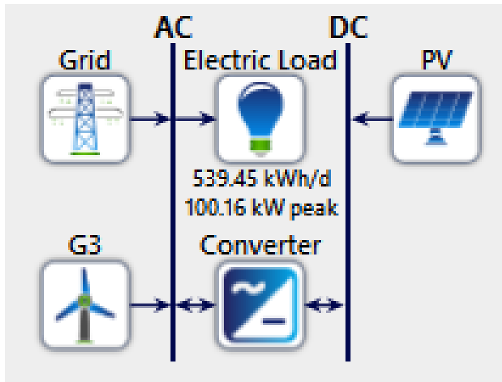


Figure 2. Diagram of a microgrid with integration of renewable energies.
Source: HOMER PRO

The use of wind energy was thought to give security and stability in the network, since it is an installation for several homes, which operates daily, and for its use (Benedicto et al., 2017; Tricase & Lombardi, 2009).

Load forecasting

In order to obtain information on the typical load and energy use for the Stone Mine sector in the city of Esmeraldas, it is planned to perform a load calculation for the area. In this study, the 5 de Agosto Parish was chosen as a contextual analysis. It is estimated that the area has 85 homes and 15 commercial premises. Burden estimation was assisted by an overview conducted through meetings and surveys. With regard to the choice of the size of the test, the interval evaluation rule has been used. Equation (7) is used to determine the sample magnitude:

$$\text{ss}=\frac{z^2 * P_{(1-P)}}{C^2} \quad (7)$$

Where:
ss → Sample size;
z → Z-score for the confidence level selected from the z-score table;
P →Standard deviation;
C →Chosen confidence interval.
The new sample size needed is calculated using equation (8):

$$ss_{new}=\frac{ss}{1+\frac{ss-1}{Pop}} \quad (8)$$

Where:
⟦ss⟧_new→New sample size;
ss →Sample size calculated from equation (7);

P_op→ The population considered in the study.

Load assessment

For the survey, all stores were chosen and, as the total number of houses is less than 100 (first rule of thumb in the sample), all houses were considered to make a more accurate load estimate. The necessary information was obtained from shop owners and house dwellers about their current energy sources and appliances. The total load demand used and its consumption (energy) were calculated as follows:

Total load (W) =Rated power (W) x Quantity, y
Total Energy (Wh) =Total Charge (W) x Hours of Use
To calculate the average load per dwelling and store, the following equation is applied:

$$Load\ house_{avr}(kW) = \frac{Demand_{Tot}\ (W)}{Houses_{Tot}\ x\ 1000w\ /kw} \quad (9)$$

Where:
$Demand_{Tot}$ → Total load demand;
$Houses_{Tot}$ →Total number of houses

To calculate the average electricity (energy) consumption per dwelling and store, the following equation is applied:

$$Energy\ house_{avr}(kWh) = \frac{Energy_{Tot}\ (Wh)}{Houses_{Tot}\ x\ 1000wh\ /kwh} \quad (10)$$

Where:
Tot Energy → Total energy consumption;
Tot Casas → Total number of houses

Table 2 presents the estimated load demand in the study area. The maximum load demanded by households and businesses is approximately 2.25 kW/day/household and 3.53 kW/day/commerce.

Table 2
Estimated load demand in the study area

Type of cargo	Per unit (kW)	Quantity	Total Cargo (kW)
Home	2.25	85	191.25
Shops	3,53	15	52.95
	Total		244.2

Table 3 presents the estimates of energy consumption in the study area. The maximum energy consumption of households and stores is approximately 8,968 kWh/day/household and approximately 10.75 kWh/day/store.

Table 3
Estimates of energy consumption in the study area.

Type of cargo	Per unit (kW)	Quantity	Total Consumption (kW)
Home	8.968	85	739.33
Shops	10.75	15	161.25
	Total		900.58

Implementation of the system
Geographical location of the site and climate database

The latitude and longitude coordinates of the study area are 0°56.8'N and 79°39.3'W respectively. These coordinates are needed to obtain insolation and wind speed data from the National Aeronautics and Space Administration (NASA) surface solar website (Twaha et al., 2012).

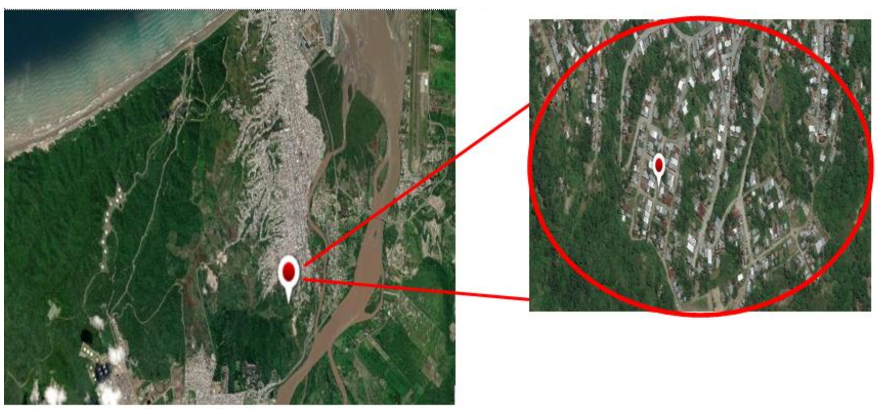


Figure 3. Location sector las Américas Esmeralda, Ecuador (0°56.8'N, 79°39.3'W.)

Energy analysis
Load profile

Figure 4 represents the hourly daily electricity demand for household and commercial loads obtained by the survey. The base load is 0.762 kW. The small load peaks of 0.531 kW occur between 6 and 8 in the morning and 3.37 kW and 1.964 kW from 18 to 21 hours. The maximum daily consumption of the study area is 244.2 kW, with an average annual energy consumption of 900.58 kWh/day.

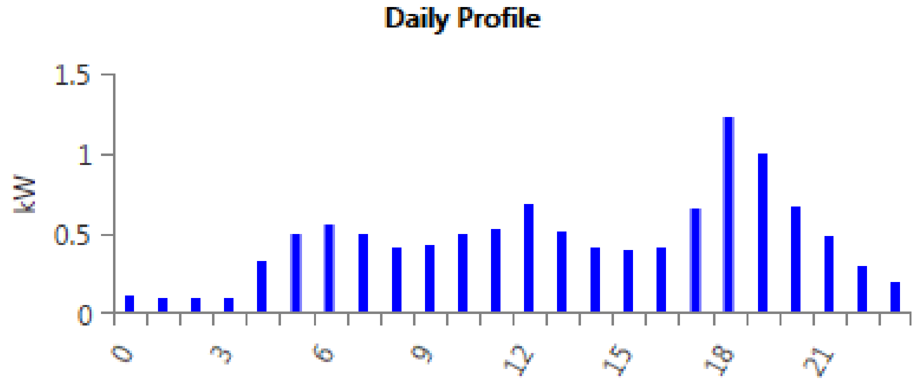


Figure 4. Daily load profile of the study area
Source: HOMER PRO

Solar radiation profile

Figure 5 represents the profile of the solar resource in the study area for approximately one year. It can be observed that the intensity of solar energy ranges from 6,240 kWh//d to 4,702kWh//d. The annual solar radiation scale is 5.46 kWh//d.$m^2m^2m^2$

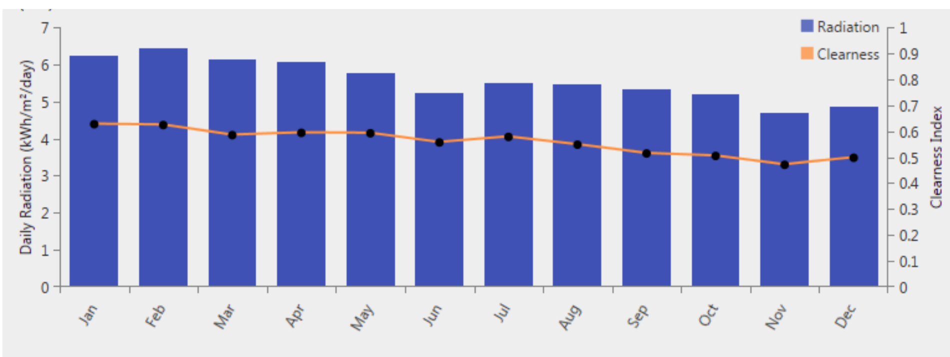


Figure 5. Average radiance values at the proposed site for microgrid installation
Source: HOMER PRO

Wind resource data

Figures 6 and 7 represent the profile of the wind resource in the study area over a period of one year. The average annual wind speed is 4.60 m/s.

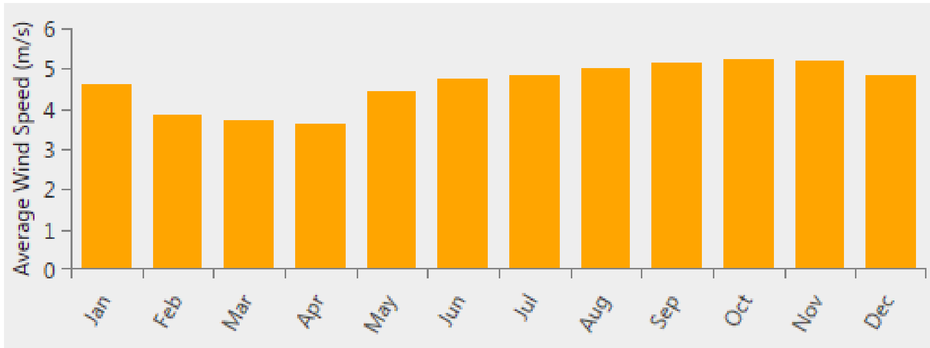


Figure 6. Average wind speed at the proposed site for the installation of the microgrids
Source: HOMER PRO

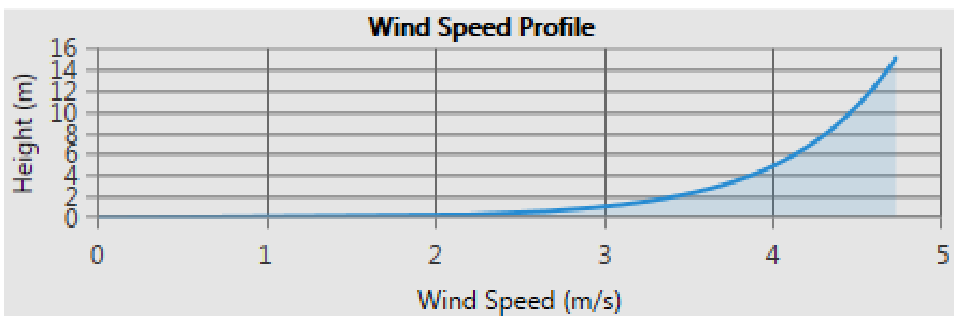


Figure 7. Wind speed profile
Source: HOMER PRO

System Computer Configuration

Information entered into the HOMER program includes; Size of the components considered, acquisition cost, replacement cost, operating cost, maintenance cost and expected service life. Table 4 shows the data used.

Table 4
System components

Component	Size	Capital Cost ($)	Replace Cost Amount ($)	O&M cost ($)	Lifetime
Generic flat plate PV	0 - 100 kilovatios	3,000.00 by kW	3,000.00 por kW	10.00	20 years
Generic 25kW Fixed Capacity Genset	0 - 300 kilovatios	175,000.00 by kW	134,000.00 por kW	5.000 by hour	50000 operating hours
Bergey Excel 10-R	25a 86 kilovatios	15,000.00 by turbine	5,000.00 by turbine	50 por año	20 years

Photovoltaic system

In photovoltaic solar energy applications, solar radiation is transformed directly into electricity by means of silicon solar cells that are electrically joined on a motherboard to constitute an energy generating set called a solar panel or array. The energy supplied by the panel is calculated from equation (11).

$$P_{PV\_out} = P_{N-PV} * \left(\frac{G}{G_{ref}}\right) * \left[1 + K_T\,(T_C - T_{ref})\right] \quad (11)$$

Where:
P_{PV_out}→The output power of the photovoltaic cell;
P_{N-PV}→ The rated power under reference conditions;
G→ Solar radiation (W /);m^2
G_{ref}→ Solar radiation under reference conditions (= =1000W /);$G_{ref}$$m^2$
T_{ref}→ Cell temperature under reference conditions (= 25° C),T_{ref}
K_T→ Temperature coefficient of maximum power (= -3.7x (1 / °C)) for monocrystalline and polycrystalline Si. The temperature of the cell is calculated using the following equation:$K_T 10^{-3} T_C$

$$T_C = T_{amp} + (0.0256 + G) \quad (12)$$

Where:
T_{amp}→ The ambient temperature.

The simulation program must accurately calculate the sizing of the photovoltaic system. According to standard practice, solar panels should be sized 10-30% above consumption to ensure supply (Madni et al., 2019; Vanek et al., 2016). The dimensions of the solar panels are 25% greater than the load. An 80% power reduction factor and a service life of 20 years have been used. Solar panels produce more energy if placed at an inclination equal to the latitude of the place (Madni et al., 2019; Vanek et al., 2016). For this study, an inclination of the panels of 10.02° has been chosen.

Wind system sizing

In wind turbines, the force of the wind passes through the aerodynamic section of the blades and the impulse that is produced causes a torsional moment that is transformed into electricity inside the wind turbine. It is basically the conversion of wind energy into mechanical energy from the turbine to finally generate electricity. We can say that the hourly energy generated (EWEG) by a wind turbine of nominal power (PWEG) is determined by the following formulas (Abdel-hamed et al., 2019; Ali et al., 2019):

$$C_{Wh} = \frac{1}{2}\, \rho_{wind} A v^3 C_P(\lambda , \beta) \text{ x } \eta_t \text{ x } \eta_g \quad (13)$$

$$E_{WEG}\,(t) = P_{WEG} \text{ x } t \quad (14)$$

Where;
ρ_{wind}→Air density;
A→Blade surface;
v→ Wind speed in m/s;
C_P→ Turbine coefficient of performance;
λ→ Ratio of rotor blade tip speed to wind speed;
β→ Blade pitch angle (degrees);
η_t→ Wind turbine efficiency

$\eta_g \rightarrow$ Generator efficiency.

For the simulation, a Bergey Excel 10-R DC wind turbine with an estimated life span of 20 years has been used.

Economic aspect

An annual real interest rate of i = 2.86% according to (3) was calculated for a nominal interest rate of i′ = 8% and an inflation rate of f = 5%. The appropriate value of this variable depends on the current macroeconomic situation, the financial capacity of the executing entity and concessional financing or other incentive policy. The Homer Grid converted the cost of capital of each component into an annualized cost, amortizing it over the lifetime, using the real interest rate (i) (Putra et al., 2020; Mora et al., 2018).

Economic analysis and reliable constraints

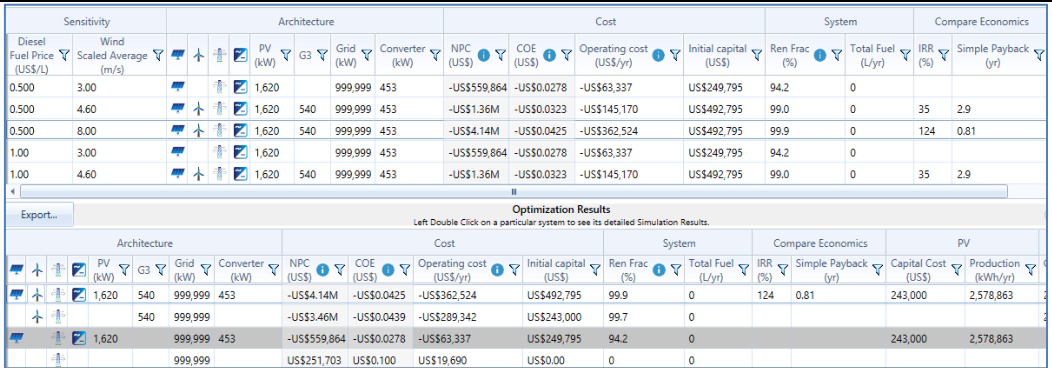
The study considered an annual interest rate of 10%, which is common in many developing countries (Kassam, 2010); The useful life of the project was considered to be 20 years. Sensitivity analyses evaluate the behavior of the system when certain parameters change value. Table 5 shows the sensitivity variables considered in this study.

Table 5
Sensitivity variables

Sensitivity variables	Values
Price of diesel (US$/L)	1.29, 2.26, 3.40
Maximum annual supply capacity (%)	5, 6, 8
Average annual wind speed (m/s)	3.637, 4.994, 5.228
Average annual solar radiation (kWh/m^2/d)	4.70, 5.46, 6.43

3 Optimization Results

The HOMER software performs a simulation of all combined system configurations in the search space and classifies viable ones based on net present value (NPV). That is, they are ordered downstream from the most profitable to the least profitable, as shown in Figure 8. The optimal system consists of one of the solar panels with a total of 1620KW, wind turbines of 540KW. The net present value (NPV) of the system is $559,864 and the value of energy (COE) is $0.0278/kWh.



Sensitivity		Architecture				Cost				System		Compare Economics	
Diesel Fuel Price (US$/L)	Wind Scaled Average (m/s)	PV (kW)	G3	Grid (kW)	Converter (kW)	NPC (US$)	COE (US$)	Operating cost (US$/yr)	Initial capital (US$)	Ren Frac (%)	Total Fuel (L/yr)	IRR (%)	Simple Payback (yr)
0.500	3.00	1,620		999,999	453	-US$559,864	-US$0.0278	-US$63,337	US$249,795	94.2	0		
0.500	4.60	1,620	540	999,999	453	-US$1.36M	-US$0.0323	-US$145,170	US$492,795	99.0	0	35	2.9
0.500	8.00	1,620	540	999,999	453	-US$4.14M	-US$0.0425	-US$362,524	US$492,795	99.9	0	124	0.81
1.00	3.00	1,620		999,999	453	-US$559,864	-US$0.0278	-US$63,337	US$249,795	94.2	0		
1.00	4.60	1,620	540	999,999	453	-US$1.36M	-US$0.0323	-US$145,170	US$492,795	99.0	0	35	2.9

Export...

Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

Architecture				Cost				System		Compare Economics		PV	
PV (kW)	G3	Grid (kW)	Converter (kW)	NPC (US$)	COE (US$)	Operating cost (US$/yr)	Initial capital (US$)	Ren Frac (%)	Total Fuel (L/yr)	IRR (%)	Simple Payback (yr)	Capital Cost (US$)	Production (kWh/yr)
1,620	540	999,999	453	-US$4.14M	-US$0.0425	-US$362,524	US$492,795	99.9	0	124	0.81	243,000	2,578,863
	540	999,999		-US$3.46M	-US$0.0439	-US$289,342	US$243,000	99.7	0				
1,620		999,999	453	-US$559,864	-US$0.0278	-US$63,337	US$249,795	94.2	0			243,000	2,578,863
		999,999		US$251,703	US$0.100	US$19,690	US$0.00	0	0				

Figure 8. The overall optimization results from HOMER
Source: HOMER PRO

Analysis of electricity production

Figure 9 shows the contribution of electricity production from various sources in the hybrid system. The photovoltaic matrix produces 82.3%, wind turbines 15.3% and the contribution from the grid is 2.45% of the total energy, respectively. The percentage of renewable energies in the system is 100%.

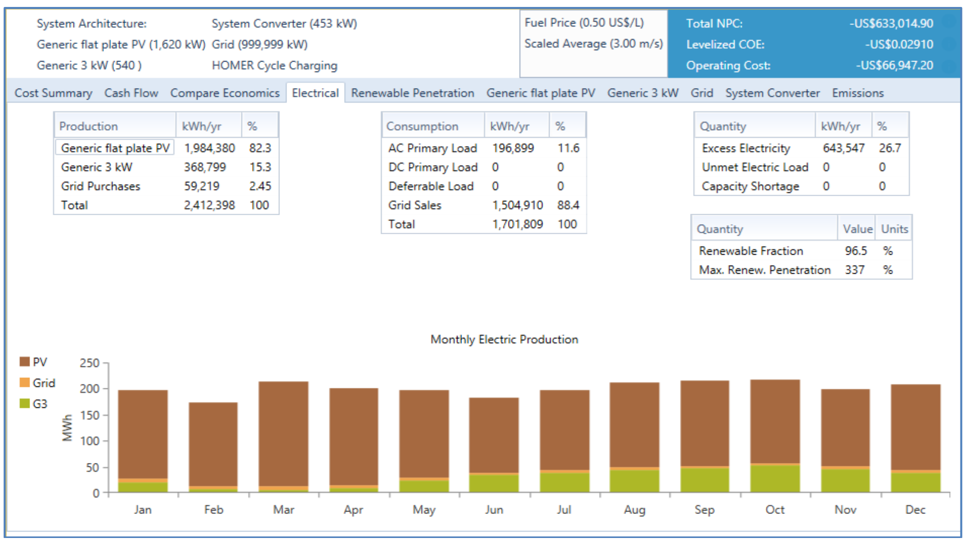


Figure 9. Contribution of various sources of electrical energy to the hybrid system.
Source: HOMER PRO

Economic metrics

Table 6 of Economic Metrics shows economic measures that represent the value of the difference between the two systems.

1. Internal rate of return (IRR or IRR) is the discount rate at which the base case and the current system have the same current net cost. HOMER calculates the IRR by determining the discount rate that makes the present value of the difference of the two cash flow sequences equal to zero.

2. Return on investment (ROI) is the annual cost savings relative to the initial investment. ROI is the average annual difference in nominal cash flows over the life of the project divided by the difference in cost of capital.
3. Simple investment payback is the number of years in which the cumulative cash flow of the difference between the current system and the base case system goes from negative to positive. The return on investment is an indication of the time it would take to recover the difference in investment costs between the current system and the base case system.

Table 6
Economic metrics

IRR	33%
ROI	29%
Simple Payback	3.0 yr

Source: HOMER PRO

Cost summary

The cost summary shows a cost comparison between the Base Case and the lowest cost/winning system.

1. The Initial Capital is the total installed cost of the system at the beginning of the project.
2. Operating Cost is the annualized value of all costs and revenues other than initial capital costs.
3. The Cost of Energy (COE) is defined in HOMER as the average cost per kWh of useful electrical energy produced by the system.

Table 7
Cost summary

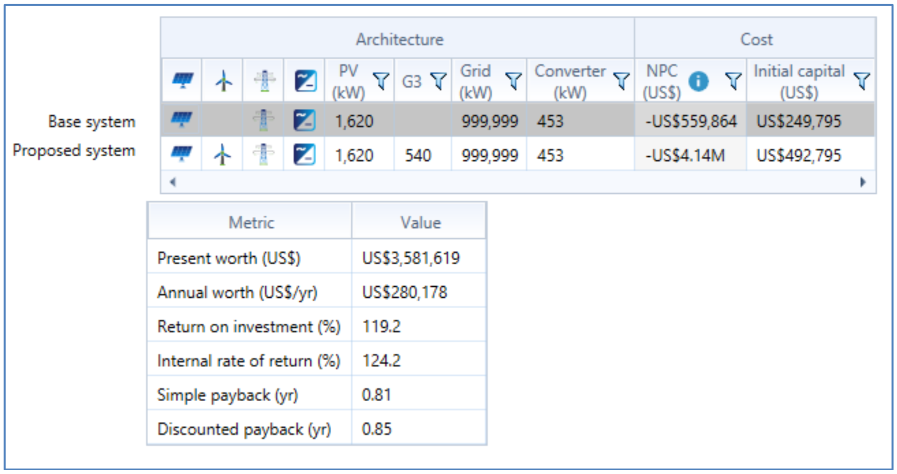
	Base Case	Lowest Cost System
NPC	US$251,703	-US$559,864
Initial Capital	US$0.00	US$249,795
O&M	US$19,690/yr	-US$63,337/yr
LCOE	US$0.100/kWh	-US$0.0278/kWh

Source: HOMER PRO

Economic comparison in simulation results

Figure 10 compares the profitability of the two systems based on the summary of cash flow obtained with the HOMER simulation software. The hybrid PV system has been considered the base case for comparison with the current system, which is the hybrid PV/wind system. The simulation results have shown that the capital cost of the current system, although high compared to the base case, has a minimum net current cost (NPV) and a minimum operating and maintenance value.

While in the base case, the initial capital cost is low, but the operating and maintenance costs are very high. This means that the current system is more cost-effective in the long run than the base case.



	Architecture				Cost	
	PV (kW)	G3	Grid (kW)	Converter (kW)	NPC (US$)	Initial capital (US$)
Base system	1,620		999,999	453	-US$559,864	US$249,795
Proposed system	1,620	540	999,999	453	-US$4.14M	US$492,795

Metric	Value
Present worth (US$)	US$3,581,619
Annual worth (US$/yr)	US$280,178
Return on investment (%)	119.2
Internal rate of return (%)	124.2
Simple payback (yr)	0.81
Discounted payback (yr)	0.85

Figure 10. Economic comparison of the base system and the current system.
Source: HOMER PRO

Environmental impact analysis

The HOMER simulation software allows an analysis of the environmental impact generating the amount of GHG (in kg/year) emitted by the modelled system. In this study, the amount of GHG emitted by the hybrid PV/wind system was compared to determine which system was more environmentally friendly. Table 8 clearly indicates that the hybrid solar/wind system significantly reduces the amount of GHG emissions.

Table 8
Annual greenhouse gas emissions

Quantity	Value (kg/year)
Carbon dioxide	57.287
Carbon monoxide	0
Unburned hydrocarbons	0
Particles	0
Sulphur dioxide	248
Óxido de nitrógeno	121

4 Conclusion

This paper briefly explains the use or application of renewable energies in microgrids, where electricity production and its integration with traditional energy systems are presented. The microgrid has the characteristics of flexible programming, good stability of the electrical system and independent operation, in addition it can be isolated and has high reliability for nearby loads. On the other hand, it is still necessary to improve the current regulatory conditions to guarantee the safe and sustainable operation of microgrids, mainly to promote such applications and commercialize hybrid systems, in terms of financing and exemptions, to improve commercial relations between customers and suppliers. Microgrids can be a good alternative to reduce electricity costs and should be evaluated in advance to ensure project reliability. The optimal system consists of one of the solar panels with a total of 1620KW, wind turbines of 540KW. The net present value (NPV) of the system is $559,864 and the value of energy (COE) is $0.0278/kWh.

The photovoltaic matrix produces 82.3%, wind turbines 15.3% and the contribution from the grid is 2.45% of the total energy, respectively. The percentage of renewable energies in the system is 100%. The capital cost of the current system, although high compared to the base case, has been shown to have a net current cost (NPV) and minimal operating and maintenance value. While in the base case, the initial capital cost is low, but the operating and maintenance costs are very high. This means that the current system is more cost-effective in the long run than the base case.

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