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GREEN LOGISTICS IN OFF-GRID RENEWABLE ENERGY PROJECTS FOR THE RURAL LOCALITIES

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Abstract- A study was conducted based on renewable energy sources, and green logistics. To implement a clean energy generation system off-grid, for the benefit of a vulnerable population in La Guajira - Colombia, which does not have 24 hours of daily electricity service. In addition, it is proposed to reduce dependence on the consumption of fossil fuels from the current generation system. The theoretical scopes are limited to estimating the energy demand of a vulnerable population, studying the behavior of the wind and solar radiation in this locality employing meteorological equipment. A correct dimensioning was proposed focused on the reduction of polluting emissions by correctly using the renewable energies of the locality. In addition, an economic balance of the investment was made.

Keywords: Green Logistics, Renewable Energy, Off-Grid Systems, Emission Reduction, Investment Costs.

1. INTRODUCTION

In recent years, the shortcomings of the electric power service for the Colombian people have been observed, identifying a group of areas located in the Colombian Caribbean as non-interconnected areas (ZNI). For this reason, one of the challenges for knowledge is to use clean energies, such as wind resources and usable solar radiation. This following the Mining-Energy Planning Unit (UPME), of which the management of the rational use of energy is related as one of the sustainable development objectives for the Colombian population [1]-[5]. Therefore, performing green logistics to design an energy system, characterizing the renewable energy potentials of a specific location, reduces the consumption of fossil fuels and consequently CO_2 emissions [6]-[18], in addition to benefiting vulnerable populations that today do not have fluid electric for an hourly autonomy of 24 hours.

Renewable energies are a new energy approach, for which various researchers have studied the effect of wind and solar behavior to design sustainable energy generating parks for both commercial and residential activities [19]-[23], the new Law 1715 of 2014 of Colombia, which promotes the use of unconventional sources of energy [24]-[28], as well as the promotion of investment by the plan of the Ministry of Environment and Sustainable Development 2020, so it is necessary to generate research addressing the use of renewable energies such as wind and solar photovoltaic energy.

One of the points to highlight are the government's goals in joint participation with the United Nations Development Program, which frame 17 Sustainable Development Goals (SDG), to generate projects with a view to global sustainability and elimination of poverty in the nation [29]-[33], of which the objective number 7 indicates affordable and clean energy, so the implementation of green logistics based on renewable energy is an important step to achieve these proposed goals.

It is the reason why in this study an energy evaluation of the Nazareth - La Guajira locality is carried out, to manage by doing green logistics, with the adequate use of renewable energies, and reduce the polluting emissions generated by consumption fossil fuel for power generation.

2. METHODOLOGY

2.1. Energy Overview of the Locality of Nazareth

The study focuses on a locality in the north of the Guajira called Nazareth, which is located northeast of the department of La Guajira in Colombia, at latitude 12°10'18"N, longitude 71°17'11"W. and an altitude of 85 m above sea level, it has an estimated number of 6 thousand inhabitants, and it has an energy generation system by solar and wind farms supported by a Diesel engine, making polygeneration.

This dimensioning carried out was carried out in 2011 in which a total of two wind turbines (WT) of 100 kW each were purchased, a total of 1,312 photovoltaic solar panels (PV), being 432 PV of 220 kWp and 880 PV of 250 kWp, a total of 28 12 kW regulators, 60 6 kW charge inverters, a total of 480 batteries distributed to 20 banks of 24 batteries, and a 364 kW Diesel plant.

In the year 2021, an extension of the system was made, presenting a total installed in PV of 430 kWp, a Caterpillar Diesel plant of 600 kW, and a total of 576 batteries of the same capacity. Figure 1 shows the energy distribution of this locality.

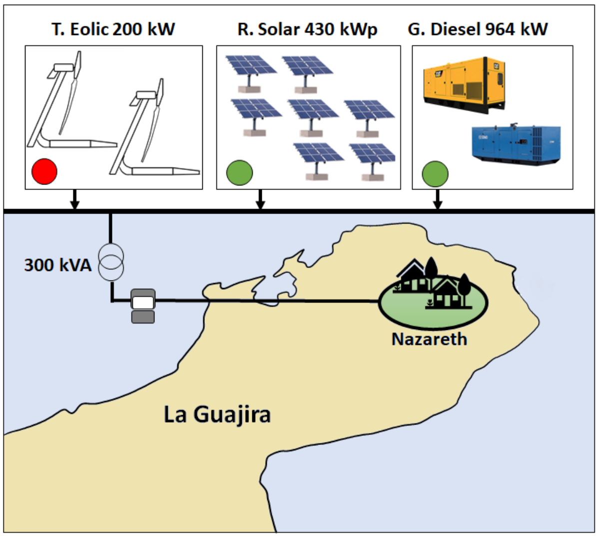

Figure 1. The current energy system of the locality of Nazareth

Another point to highlight is that the autonomy of the generation park only reaches 10 hours a day of service to the community. Once the sunlight ceases, and the batteries are discharged, the Diesel generators operate to recharge them, this being a constant and daily consumption of fossil fuels, increasing the carbon footprint due to polluting emissions by consuming 96 gallons of fuel per day.

The fuel must be transported from a station far from the town, which generates additional transport costs.

2.2. Wind Power in the Locality

Using the specialized instrumentation provided by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), the analysis of the annual wind behavior was made with data recorded from the years 2011 to 2019, the calculation model of Hellman's law is used to determine the wind speed at different heights, using a constant obstruction to the passage of the wind [34].

$$\frac{v}{v_0} = \left(\frac{h}{h_0}\right)^{\alpha} \tag{1}$$

where, V is the projected wind speed, V_0 is the wind speed at a reference height h_0 of 10 m, h is the projection height, and α is the wind obstruction constant.

2.3. Solar Energy in the Locality

Solar energy was evaluated using the atmospheric transmittance methodology, which is determined through a set of calculations that considers radiant dispersion and intermittency [35]-[37]. To implement this methodology the following set of equations is used:

$$I_{Total} = I_D + I_{Dif} \tag{2}$$

$$I_D = 0.97 C_s \tau_r \tau_o \tau_g \tau_w \tau_a \sin(A) \tag{3}$$

$$I_{Dif} = I_r + I_a + I_m \tag{4}$$

$$I_r = 0.395 C_s \tau_o \tau_g \tau_w \tau_{aa} \sigma_m \tag{5}$$

$$I_a = 0.79 C_s \tau_o \tau_g \tau_w \tau_{aa} \sigma_m \left(0.93 - 0.21 \ln(m_{air})\right) \tag{6}$$

$$\sigma_m = \frac{(1 - \tau_a / \tau_{aa}) \sin(A)}{1 - m_{air} + m_{air}^{1.02}} \tag{7}$$

$$I_m = \left(I_D \sin(A) + I_r + I_a\right) \frac{\rho_g \dot{\rho}_a}{1 - \rho_g \dot{\rho}_a} \tag{8}$$

where, I_T is the estimated total solar irradiation in W/m^2, $I_{D,}$ and I_{Dif} are the direct solar irradiation and diffuse solar irradiation respectively, C_s is the daily solar constant, τ_r is the transmittance by molecular scattering, τ_o is the transmittance by ozone absorption, τ_g is the gas mixture absorption transmittance, τ_w is the vapor absorption transmittance, τ_a is the absorption and scattering transmittance due to aerosols, A is the solar altitude angle, d_J represents Julian days, and m_{air} is the air mass.

The I_r is the irradiation component due to the molecular dispersion of the air, I_a is the irradiation component due to the existence of particulate dust in the air, I_m is the irradiation component due to reflection from the soil and the atmosphere, ρ_g is the reflection coefficient surface, ρ_a coefficient for multiple reflections between ground and sky [38].

Then the peak solar hours (HS) are determined by dividing the obtained value of I_T by an irradiance value of 1 kW/m^2.

2.3. Investment and Green Logistics

The main components that are evaluated in the development of the project are the cost-benefit ratio and the reduction of the carbon footprint. The evaluated elements indicate a fuel consumption for transportation from the station to the locality and its return, and the fuel consumption used in the generation plant. The feasibility of projecting the generation of energy for the locality to a totality of renewable energy is evaluated to minimize polluting emissions.

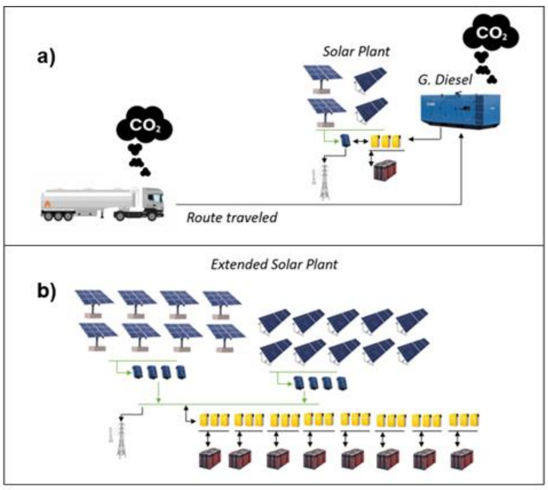

Figure 2. Generation plant a) Current system, b) Extended solar plant

Figure 2 above shows in part a) an overview of the generation of polluting emissions included in the power generation process for the study location, in contrast to part b) where the emissions generated are minimized by increasing use. of sustainable energy by extending the solar plant.

Therefore, calculating the Net Present Value (NPV) of the costs incurred in the purchase of energy is presented to establish the outlook of expenses, when using fossil fuels to generate energy, when compared to replacing this system for a total generation with renewable energies, by adapting more PV systems or WT systems [39].

Projects that venture into the use of sustainable energy use the NPV method, the Internal Rate of Return (IRR) to establish a decision tree in which the option with the highest cost-benefit is established in different scenarios.

$$NPV = \sum_{t=1}^{n} \frac{F.C_z}{(1+IRR)^z} - I_0 = 0 \quad (9)$$

where, I_0 is the value of the initial investment of the project, and $F.C_z$ represents the cash flow for year z.

3. RESULTS AND DISCUSSION

What was evaluated in this system shows that the WTs, which are the equipment with the highest installed cost, did not come into operation due to improper dimensioning of the wind behavior, the average wind speed projection is 10 m/s for these pendular type WTs single blades do power generation. Figure 3 below shows the behavior of the wind obtained for this locality.

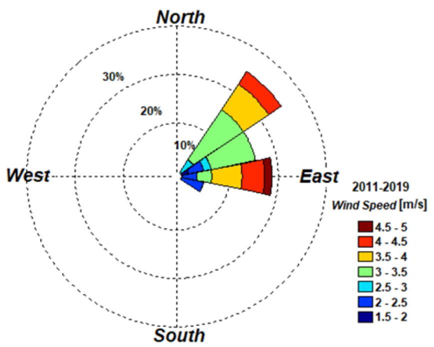

Figure 3. Nazareth locality wind rose

As observed in Figure 3, the maximum ranges of wind speed in the locality are a maximum of 5 m/s in an easterly direction, and an average of 3 m/s at 3.5 m/s of wind speed. These values are obtained for a reference height of 10 m. Applying equation 1, the wind speed is projected according to the height, in the figure below.

The Figure 4 above indicates that the wind speed reaches values of 5.2 m/s at a height of 50 m, and a value of 6.4 m/s at a projected height of 100 m. validating why the installed WT did not enter the operating range. For the solar potential, applying equations (2) to (7) gives the projected solar radiation from 2010 to 2020 for the locality.

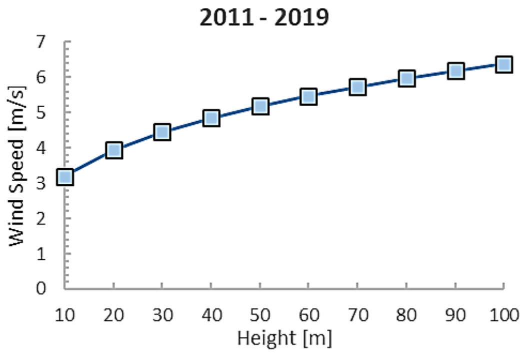

Figure 4. Wind speed at different heights in the Nazareth locality

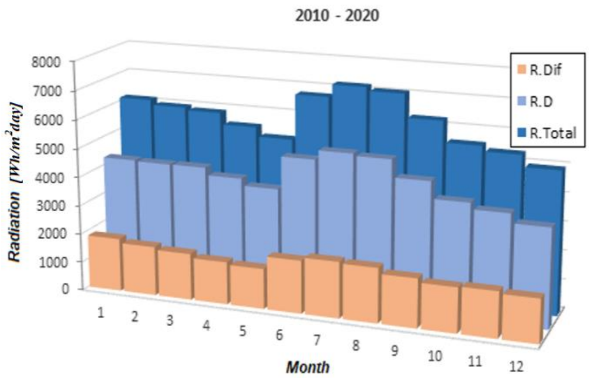

Figure 5. Solar radiation of the Nazareth locality

The minimum value for the critical month of solar radiation is taken, to size the photovoltaic systems. This value is equivalent to 5 kWh/m^2 day for an estimated HS corresponding to 5 hours. Thus, the extension of the dimensioning is adequate for employing PV systems.

From the consumption data, it can be highlighted for a day of maximum consumption provided by the National Monitoring Center (CNM) that for a peak day of energy used, values of 1.5 MWh/day are reached, which would reflect a maximum monthly peak of 45 MWh/month for an approximate of 6 hours of daily service. The amount of power used oscillates between the values of 220 kW and 250 kW.

The current dimensioning operates with 430 kWp in PV devices and a 964 kW diesel engine thermal generation support, used to recharge the batteries. Solar generation when related to HS gives a total of 2.15 MWph/day ideal available, this being 64.5 MWph/month. Giving an approximate 6 to 10 hours of autonomy when using a battery system that has 576 units each of 3350 Ah and 2 V. These batteries are connected in series to obtain 48 V so that 24 batteries are grouped into 24 separate benches.

For the requirement of 24 hours of daily energy sustainability, consumption would be presented for 5195 kWh/day, and with the availability of 5 HS, 1039 kWp installed will be needed. So, the solar park would be extended to a greater amount of PV.

With additional references of 340 Wp modules with open-circuit voltage (V_{oc}) of 47.50 V, and short circuit current (I_{sc}) of 9.22 A. Knowing that the extension corresponds to an additional 609 kWp, 1792 PV will be needed. Now the calculation of regulators is established. To maintain homogeneity, the same brand and capacity of regulators are chosen as the current dimensioning. These regulators feature the following Sunny Tri-power 12000TL brand feature with 98% efficiency.

$$N_{reg} = \frac{609\text{kWp}}{12\text{kW} \times 0.98} = 51.8 \qquad (10)$$

For approximately 52 regulators, distributed for PV strings up to a maximum voltage of 1000 V with a minimum current of 33 A and a maximum current of 66 A for the regulator. Allowing then a maximum of 21 PV in series and 4 to 7 parallel connections per array. obtaining:

56 solar arrays 8 PV strings connected in series and 4 connections in parallel. 4 additional regulators are increased to balance. The cost of the wiring will be limited to currents to a maximum of 36.9 A, in addition to the short circuit protection.

The sizing of batteries would be designed for the surplus with a value of 3045 kWh/day, and maintaining homogeneity with the current bank, it is designed for 48 V maximum discharge percentage of 50% and 1 day of autonomy.

Obtaining as a result 38 additional battery banks, connected 24 batteries in series of capacity OPzS 2V 3350 Ah, for a total of 912 additional batteries.

In the same way, homogeneity is made with the selected inverters for 3 Sunny Island 8.0H 6 kW inverters connected in parallel for each battery bank, thus being 114 additional inverters.

Table 1. Equipment and costs for project extension

Equipment and more	Units	Cost per unit [USD]	Total cost [USD]
Photovoltaic panels	1792	200	358.400
Regulators	56	2.800	156.800
Investors	135	3.800	513.000
Batteries	912	1.130	1.030.560
Protections	224	27	6.048
Cabling [100 m]	37	350	12.950
Connectors	1983	12	23.796
Ground transportation			14.000
Brackets			32.000
installation			512.000
Total			2.659.554

Table 1 shows a projection of the investment costs of the project, indicating costs of equipment, transportation, and implementation of the proposal.

In Figure 6 below, a graph of investment costs for the energization of the locality of Nazareth is shown. Where income from the sale of electrical service and costs associated with maintenance are included. Series A will be named to the line that represents the current system, and Series B will be named to the line that represents the implementation of the project with renewable energies and green logistics. This is to facilitate the analysis.

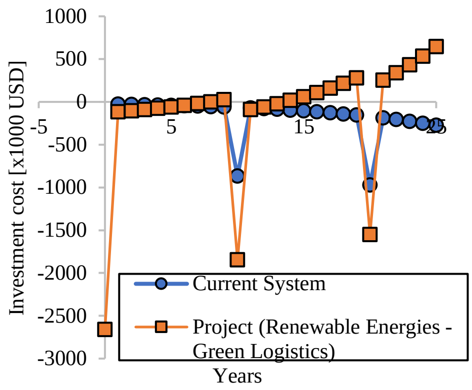

Figure 5. Solar radiation of the Nazareth locality

Series A is based on the current system, which uses daily fossil fuels as support to charge the batteries of the photovoltaic system, however, this system only provides 10 hours of daily electrical service to the inhabitants.

Series B eliminates dependence on fossil fuels by extending the use of renewable sources or clean energy, grants a 24-hour autonomy of electrical service to the inhabitants, and regarding dependence on fossil fuels. A reduction of 1.145 tCO_2 per day or 412.2 tCO_2 per year is obtained by not using the gallons of fuel per day in the Diesel plants, this being one of the factors that favor the viability of the energization project with sustainable energies.

The peaks shown in Series A and Series B represent the purchase, transportation, and installation of battery banks since these have a duration of approximately 10 years. It should be noted that in Series A it is limited to the current bank of batteries, and Series B to all batteries combining the current ones and the extension.

Another important note is that these projects are carried out for the benefit of a vulnerable population, and made by government entities, so they are not carried out with the purpose of obtaining economic profits.

4. CONCLUSIONS

The research was carried out to improve the quality of life of the inhabitants of a vulnerable population, which only has 10 hours of daily electricity service.

The results show the high viability of the execution of a proposal, based on the use of clean energy and the reduction of polluting emissions.

It is possible to size a system that grants 24 hours of autonomy of electric service, reducing dependence on fossil fuels.

Investment costs show high profitability over the years. By focusing the project on green logistics, an interesting proposal was achieved that uses renewable energy as a base.

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