Feasibility study of a hybrid solar photovoltaic-biomass system in El Cedral, El Paraíso, Honduras

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ABSTRACT. Introduction: Not having a continuous and safe electricity supply hinders the development of basic human and labor activities. The objective of this research is to determine the technical and economic feasibility of a hybrid solar photovoltaic- biomass system for the generation of electricity in a coffee mill and residential self-consumption to supply electricity to a producer in the community of El Cedral, department of El Paraíso, Honduras. Methods: For the study, load profiles were carried out to determine the demand and electricity consumption of the home and coffee processing. Considering the energy resources available in the area, the scenarios to be studied were dimensioned, analyzing the technical and economic feasibility of each one of them. With this information, the scenarios were compared, and the environmental advantages of its installation were analyzed. Results: The daily consumption of the house is 7.13 kWh and 9.43 kWh. The hybrid system managed to cover energy consumption and 25.43 kg of CO_2 was emitted per year due to the energy change. Conclusions: Two of the three proposed scenarios presented technical feasibility with levelized energy costs (LCOE) lower than the current residential electricity tariff in Honduras corresponding to $ 0.20 /kWh, also, they presented sufficient area for their installation. Finally, the kilograms of CO_2 no longer emitted into the atmosphere due to the change from use of fossil fuels to renewable energy sources to feed a pulper were calculated.

Key words: Hybrid system, electric power generation, technical feasibility, economic feasibility, levelized cost of energy.

I. INTRODUCTION

Electric power coverage represents a cross-cutting axis for human development. According to the Observatory of Energy, Technology and Infrastructure for Development [1] the human development index (HDI) is related to the consumption of electrical energy per capita in a country, such as Norway, which is the country with the highest HDI with 95.40% in 2018 and a per capita consumption of 23,000 kWh, and Honduras ranks 132 of the countries with the highest HDI with 62.30% [2] with a per capita consumption of 620 kWh [3]. The supply of this basic resource to the population allows a sustainable social and economic development for the development of daily activities such as cooking and storing food, carrying out work using machinery and the use of various electrical appliances. From a general perspective, the supply of electrical energy allows a comprehensive development of societies.

In Honduras, the electricity coverage index (ICE) for the year 2019 was 85.02% [4]. One of the departments with the lowest ICE is El Paraíso, where for the same year, 2019, 35.79% of the population of this department did not have access to electricity. In addition, the department of El Paraíso is the department with the largest area of cultivated coffee, 557.8 km² and 15,925 coffee producers for the year 2020 [5]. This research will be carried out for a coffee producer located in the community of El Cedral, department of El Paraíso, where at present there is no electricity supply from the national grid that meets the needs of both, the home, and the coffee mill, which currently they have a 330 W photovoltaic module that is not capable of meeting the demand for electrical energy.

This research seeks to determine the technical and economic feasibility of a solar photovoltaic-biomass hybrid system. In addition, it is sought to determine through the approach of three different scenarios, (1) scenario with SFV (solar photovoltaic) system, (2) scenario with biomass and (3) hybrid solar photovoltaic- biomass scenario. Which one presents the best technical feasibility through the evaluation of the capacity to cover the power demand and electric energy consumption, in addition to the availability of the area to implement the systems and economic feasibility through the calculation of the LCOE that allows a continuous and safe supply for the benefit of an integral development that provides better living conditions for workers and people in charge of the place.

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II. METHODOLOGY

The technical and economic feasibility analysis of each proposed scenario was carried out as follows; First, the consumption of the location was determined, next, the available resources were investigated and then, the technical feasibility of the proposed scenarios were studied. That is, if they generated enough electrical energy to cover the energy consumption of the house, this will be technically feasible. Finally, the economic study was developed, which determined feasible those that the LCOE is less than the cost of electricity from the SIN.

A. Obtaining electrical charge profiles.

Data was collected on the nominal power of the appliances and machinery used in the location, as well as the hours of use of each and the time of use of each load. The power demand of the house and coffee mill was calculated every 15 minutes.

B. Primary Resources Available.

The location has a daily-horizontal solar radiation of 5.06 kWh/m^2/day [6] and a variety of available organic resources such as cow and chicken manure, coffee honey waters, coffee pulp. The organic matter used will be cow manure, which has 632 kg per day.

C. Sizing of the photovoltaic solar system.

The annual electrical energy consumption was determined through a load of profiles. With this data, we proceeded to calculate the modules necessary for the system with a nominal power per module of 400 W, a PR of 75% and a received irradiation of 1,687.2 kWh/m^2 [7]. Formulas 1 to 7 were used to size the photovoltaic system [8].

$$Number\ of\ modules = \frac{Demanded\ energy}{Irradiation\ received * P.R * Nominal\ Power} \text{ [8]}$$

Equation 1- Number of photovoltaic modules.

Upon obtaining the number of modules required, the nominal power AC and the ratio DC/AC were calculated using the following equation,

$$Ratio\ DC/AC = \frac{Rated\ capacity\ DC}{Rated\ capacity\ AC} \text{ [8]}$$

Equation 2- Normal DC and AC capacity.

Knowing the nominal power, AC, the inverter is selected, since the data in its technical sheet will be used in the following equations for the minimum and maximum number of recommended modules,

$$Minimun\ voltage\ of\ the\ PV\ module = V_{mp} + (T_{average} + T_{rise} - T_{STC}) * \frac{TC_{Pmax}}{100} * V_{mp} \text{ [8]}$$

Equation 3- Minimun voltage of the photovoltaic module.

$$Maximun\ voltage\ of\ the\ PV\ module = V_{oc} + (T_{minimun} - T_{STC}) * \frac{TC_{Voc}}{100} * V_{oc} \text{ [8]}$$

Equation 4- Maximun voltage of the photovoltaic module.

$$Minimun\ number\ of\ modules = \frac{V_{\min(MPPT)} inverter\ input}{Minimun\ voltage\ PV\ module * (1 - Degradation\ factor\ at\ 25\ years)} \text{ [8]}$$

Equation 5- Minimun recommended number of modules.

$$Maximun\ number\ of\ modules = \frac{V_{\max(MPPT)} inverter\ input}{Maximun\ voltage\ of\ the\ PV\ module} \text{ [8]}$$

Equation 6- Maximun recommended number of modules.

Finally, it is necessary to perform the calculation of the recommended maximum of strings in parallel.

$$Recommended\ maximun\ number\ of\ strings\ in\ paralle = \frac{Inverter\ rated\ current}{Maximum\ current\ solar\ module\ power\ @STC}$$

Equation 7- Maximum recommended number of strings in parallel.

Having calculated the parameters of the photovoltaic modules, the battery field must be sized with data on the daily consumption of electrical energy, the number of days of autonomy (which must be a minimum of three days), the system voltage Accumulator determined according to the nominal DC power and the maximum depth of discharge of the batteries, this oscillates between 60-80% of its charge capacity [10].

$$CS = \frac{E_C * N}{V_{SB} * P_d} \text{ [9]}$$

Equation 8- Battery field dimensioning.

As a last parameter, calculations of the input and delivery current of the regulator were carried out for its selection, for this the following formulas were used:

$$I_{in} = 1.25 * I_{sc} * N_p \text{ [9]}$$

Equation 9- Regulator input current.

$$I_{out} = 1.25 * \left(\frac{\frac{P_{INV}}{n_{INV}}}{V_n} \right) \text{ [9]}$$

Equation 10- Regulator delivery current.

D. Sizing of the biomass system.

Biogas production is obtained through anaerobic digestion which takes place inside the biodigester and depending on the temperature of the location, it will have a variable load retention time. For a temperature of 24.2 °C the retention time is 25 days [11].

Since the biodigester studied is continuous flow, the mixture that will be entered as a daily load will be a ratio of 1:3, for each kilogram of cow manure, three liters of water.

Normally the volume in the liquid phase is 75% of the total volume of the biodigester, the remainder will be the volume in the gas phase, therefore, the total volume of the biodigester is calculated as follows:

$$V_T = V_G + V_L \text{ [10]}$$

Equation 11- Biodigester volume.

Organic matter is made up of two parts, water and total solids. Total solids break down through anaerobic digestion and produce biogas. Total solids have a faction of matter known as volatile solids that allows the amount of biogas to be produced to be determined in the same way.

Depending on the organic matter, the percentage of these varies. Volatile solids are calculated with the following equation:

$$V = TS * \%VS \; [11]$$

Equation 12- Volatile solids inside the biodigester.

To determine biogas production, the amount of volatile solids in the biodigester was taken into account and multiplied by a factor of biogas production per cow manure of 0.27 [12].

E. Hybrid system Sizing.

For the sizing of the hybrid system, the equations and procedures previously used in sizing the photovoltaic solar system and the biomass system were used.

F. Analysis of economic feasibility of the scenarios.

For the scenarios that presented technical feasibility, the economic feasibility was determined by calculating the LCOE, which, since it is less than the current electricity rate in Honduras, equivalent to $ 0.20 for July 2021, is considered feasible [13].

$$\text{LCOE} = \sum_{n=1}^{m} \frac{Capital\ cost_n + O\&M}{Generated\ energy_n} \; [14]$$

Equation 13- Levelized Cost of Energy (LCOE).

G. Analysis of environmental benefits.

The environmental advantage was considered due to the change from fossil fuels to feed a coffee pulper in the cutting season to feed it with renewable energy sources. For this calculation, the following equation corresponding to the kilograms of CO_2 emitted into the atmosphere was used, taking the amount of electrical energy that the pulper consumes annually and the emission factor in Honduras of 0.37 [14].

$$Energy\ Consumption * Emission\ Factor = kg\ de\ CO_2\ emitted$$

Equation 14- CO_2 not emitted by switching from fossil fuel to electrical energy.

III. Results

A. Results of load profiles obtained.

Two load profiles were obtained, in (1) off-cut season during the months of January to November, without the use of a pulper, consuming 7.13 kWh per day with a maximum power demand of 0.34 kW, and (2) outside of cutting season during the month of December, using the coffee pulper, consuming 9.43 kWh per day with a maximum power demand of 1.04 kW. Consumption is frequent from Monday to Sunday.

B. Primary Resources Available.

From the available resources mentioned in the methods, cobs and coffee pulp were discarded due to their classification as lignocellulosic biomass which is used in thermochemical transformation, unlike the rest of the available organic matter classified as wet residual biomass used for anaerobic processes as carried out in this research. [15]. Chicken manure was discarded due to the bibliography available used for the calculation of gas production by anaerobic process which only contained the kilograms of manure by every 100 kg of weight and the physicochemical characteristics of animals like cows, pigs, goats, rabbits, horses and humans [12].

For this research, only 632 kg of cow manure per day were used, of which only 200 kg will be used because the cow manure is 8% of its weight.

In addition, the 12 cows are grazed meanwhile from the bull there is a 100% of defecated organic matter obtained.

Martí (2019) states that: "from the grazed cows only 25% of the defecated organic matter is recovered" (p.27). [12] Coffee Honey Waters were also used in the cutting season, their energy potential was not considered, it was only considered as part of the liquid volume for the biodigester.

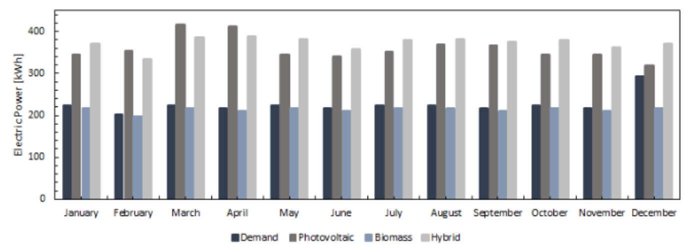

Fig. 1 Electric power generation versus electric power consumption.

C. Results by scenario: Sizing photovoltaic solar system.

By means of equation 2 it was determined that 7 photovoltaic modules of 400 W will be necessary, obtaining a nominal DC power of 2,800 W. A 2,500 W nominal power inverter will be used. Thus, obtaining a DC/AC ratio of 1.12.

Using equations 7 and 8, the maximum and minimum number of photovoltaic modules to be installed were calculated for the inverter to work in the MPPT range (maximum power point tracker). Obtaining an arrangement of seven modules in series, a maximum input voltage of 359 V, and a chain, a maximum input current of 10.76 A.

[10] (Mundo Renovable, 2021) mentions that, being in a non- electrified rural area, the best selection of batteries for storing electrical energy are gel batteries, due to their behavior in the face of deeper discharges. For this reason, 24 Tensite batteries connected in series of 820 Ah and 2 V will be used.

Using equations 15 and 16 it was determined that a 66.84 A charge regulator will be necessary. Selecting the Victron Energy 450|100 model according to the charge regulators found in the market.

The system will generate 11.96 kWh per day on average, with a system area of 13.9 m^2.

D. Results by scenario: Sizing of the system with biomass.

By calculating the biogas production carried out with the equations proposed in the methodology, it was determined that the system only with biomass does not present technical feasibility. The electrical energy consumption at home and coffee mill ranges from 7.13 kWh to 9.43 kWh of which the biodigester is only capable of providing 7.00 kWh in the most critical condition.

E. Results by scenario: Sizing of the hybrid system.

The hybrid solar photovoltaic system presented technical feasibility. There is 7.00 kWh/day, obtained from biogas in the most critical condition, in addition, there are 118.05 m^2 available for the installation of the biodigester, of which only 7.73 m^2 were needed.

Through the photovoltaic solar arrangement, it was possible to supply the electrical energy necessary to cover the consumption of 4.05 kWh per day that is not capable of covering the biogas. With this generation of daily energy, the system is capable of supplying the electrical energy consumption of the home and coffee mill and it is also capable of providing electrical energy to critical loads through the battery bank in case of days when the system presents a low production, in addition, there is a ceiling area of 120 m^2 of which only 5.4 m^2 were needed for the installation of three modules of 400 W each.

Figure 1 shows the generation of the three proposed scenarios and the consumption of the home and coffee mill for one year. The generation by the biomass system does not cover the energy consumption of the house.

F. Economic feasibility analysis.

The photovoltaic solar scenario presented economic feasibility as the LCOE was $ 0.11 /kWh, lower than the current electric power rate equivalent to $ 0.20 for July 2021 and a specific cost of $ 3.79 /kWp.

The scenario with biomass, as it did not present technical feasibility, did not proceed to carry out the economic feasibility calculations.

The solar photovoltaic-biomass hybrid scenario presented economic feasibility as the LCOE was $ 0.09 /kWh, lower than the current electricity rate equivalent to $ 0.20 for July 2021 and a specific cost of $ 3.04 /kWp.

G. Analysis of environmental benefits.

The coffee pulper consumes 2.28 kWh corresponding to daily use during the coffee season in December. Consuming 68.4 kWh per year that are powered by fossil fuels. By switching to renewable sources, it was calculated that 25.43 kg of CO_2 would stop being emitted.

IV. Discussion

Feasibility of the three scenarios presented was obtained. The first scenario, a photovoltaic solar system, presented technical feasibility by being able to supply the demand and cover the daily electricity consumption of 7.13 kWh on non-cutting days without using a pulper and 9.43 kWh on cutting days, using a pulper. This result is due to the oversizing of 20% of the electrical energy consumed, since this house and coffee mill are located in a non-electrified rural area, the oversizing proved to be a key factor in providing a safe and continuous supply to these places. In addition, the area presented availability of sufficient ceiling area for the installation of the modules, with a ceiling area of 120 m^2 of which 13.9 m^2 were used.

The biomass scenario did not present technical feasibility because the amount of available organic matter was not enough to generate the amount of biogas necessary to cover the demand for electrical energy in the home and coffee processing. The daily consumption of the home and coffee mill varies throughout the year between 7.13 kWh and 9.43 kWh and the biodigester, according to the methodology used, produces 3.5m^3 of biogas equivalent to 7.00 kWh in the most critical situation [11]. This result is due to the fact that, of the 632 kg of organic matter available, only 200 kg were used per discard according to the type of biomass and conversion technology to be used. In this case, the cobs were discarded because they are lignocellulosic biomass which is usually used for thermochemical transformation, leaving chicken manure, coffee pulp, honey water and cow manure which are classified as wet or fermentable residual biomass which is subjected to an anaerobic process as in this investigation. [15]. However, only the coffee honey waters were used without considering its energy potential, it was only taken as part of the liquid volume for the biodigester. In addition, cow dung was used, which presented several reductions due to cow grazing.

The hybrid scenario presented technical feasibility as it was able to supply the demand for power and daily electricity consumption. The distribution of the technologies is as follows: the biomass system supplies 5.65 kWh per day and covers a land area of 7.73 m^2 out of the 118.05 m^2 available. The photovoltaic solar system supplies 4.05 kWh and uses a roof area of 5.4 m^2 out of the 120 m^2 available. The sum of the energy production from these sources is enough to cover the electrical energy needs of the home and coffee processing, in addition, the photovoltaic solar component through the 20% oversizing is capable of providing electrical energy to critical loads on critical days of low power generation.

Figure 2 shows the distribution of electricity consumption by technology throughout the days that are outside the cutting season and during the cutting season. It is also observed the moment in which the photovoltaic solar generation exceeds the consumption of the home and coffee mill and begins to charge the batteries.

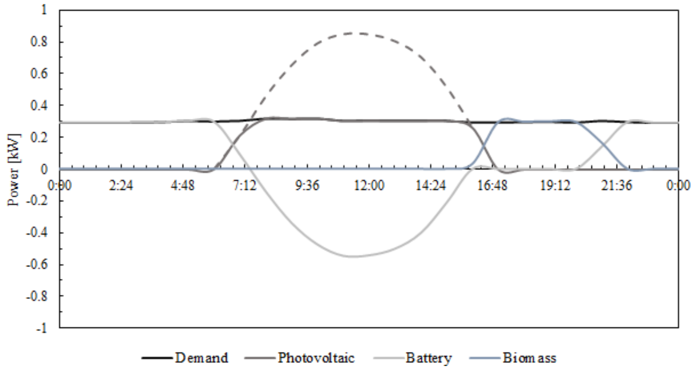

Fig. 2 Distribution of electricity consumption by daily technology in off-peak season.

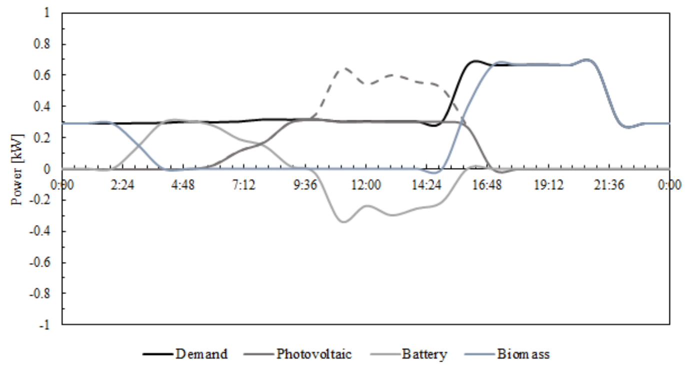

Fig. 3 Distribution of electricity consumption by daily technology in the off-season.

The economic feasibility of the solar photovoltaic and hybrid system scenarios were determined as the LCOE of these was lower than the current electricity quote in Honduras, corresponding to $ 0.20 for July 2021. The LCOE of the solar photovoltaic system corresponding to $ 0.11 /kWh was higher than that of the hybrid solar photovoltaic-biomass system corresponding to 0.09 kWh. The difference between the LCOE obtained lies in the number of batteries to be used, for the photovoltaic solar system, twenty-four batteries of two volts each were used at a price of $ 268.06 each, this being the most expensive component of the system, while for the hybrid system required two twelve-volt batteries at a price of $ 476.07 each, in addition, four modules were needed, unlike the scenario with only the photovoltaic solar system where seven modules were used, each one under a price of $ 165.41. Another element that influences this calculation is that the photovoltaic solar component of the hybrid system has a lower DC nominal capacity and therefore a lower AC nominal capacity, so the inverter used is of lower capacity and has a price of $ 328 compared to the Solar photovoltaic only scenario where the price of the inverter is $ 1,142.23.

TABLE I

DESCRIPTION OF COSTS OF THE PHOTOVOLTAIC SOLAR SYSTEM

Description	Quantity	Unit Price	Total
Photovoltaic Solar System			
Solar Inverter	1	$1,142.23	$1,142.23
Canadian Solar 400W Module	7	$165.41	$1,157.87
Battery Ultracell 2v 690 Ah	24	$268.06	$6,433.44
JYFT 10 AWG Wiring	2	$19.99	$39.98
Iron Ridge structure	1	$443.83	$443.83
Regulator MPPT 150V 60A	1	$353.38	$353.38
Equipment setup cost	1	$836.55	$836.55
Equipment transportation cost	1	$209.14	$209.14
	Total Cost [$]		**10,616.42**
	Specific Cost [$/Wp]		**3.79**

TABLE II

DESCRIPTION OF COSTS OF THE HYBRID SYSTEM

Description	Quantity	Unit Price	Total
Photovoltaic Solar System			
Solar Inverter	1	$328.00	$328.00
Canadian Solar 400W Module	3	$165.41	$496.23
Battery BAE Secura 12V 167 Ah	2	$476.07	$952.14
JYFT 10 AWG Wiring	1	$19.99	$19.99
Iron Ridge structure	1	$178.33	$178.33
Regulator MPPT 150V 60A	1	$353.38	$353.38
Equipment setup cost	1	$836.55	$836.55
Equipment transportation cost	1	$209.14	$209.14
Biomass system			
6 inch PVC pipe	2	$22.00	$44.00
Solar tent	32.5	$52.00	$1,690.00
1/2 inch PED or PVC irrigation tubing	25	$16.33	$408.25
PVC Elbow	2	$4.20	$8.40
PVC Tees	4	$5.10	$20.40
120 liter plastic containers	6	$67.38	$404.28
Tire league	60	$15.00	$900.00
300 micron tubular polyethylene	20	$3.60	$72.00
Valves	2	$41.00	$82.00
Workforce	6	$42.80	$256.80
Generator	2	$480.00	$960.00
	Total Cost [$]		**8,219.89**
	Specific Cost [$/Wp]		**3.04**

It should be noted that the materials necessary for the biodigester do not have more technology and present prices lower than the cost of materials for photovoltaic solar systems. Under this analysis it can be said that the LCOE of the hybrid system is lower because the number of materials for the photovoltaic solar system is reduced since part of the energy is supplied by the biodigester, thus obtaining the highesteconomic feasibility of the three scenarios.

The environmental advantages obtained in this study are due to the change in the use of fossil fuels to feed a pulper with renewable sources, for this calculation the emission factor of Honduras was used, obtained with the percentage corresponding to the generation of energy based on fuels.fossils equal to 37.18% [16] this was multiplied by the amountof kWh consumed by the pulper, corresponding to 745.7 kWh for three hours during a month. A total of 25.43 kg of CO_2 wasobtained, which would no longer be emitted into the atmosphere.

Other hybrid systems using the same technologies have obtained feasible results, such as the feasibility study carried out in the department of Chocó, Colombia. Where electricity was supplied to an area that was isolated from the electricity grid. It was possible to cover a consumption of 33.3 MWh through the proposed hybrid solar photovoltaic-biomass gasification system. [17].

A similar study carried out in 2018 shows how solar photovoltaic systems can be complemented with other power generation systems. Photovoltaic generation has its potential in hours of the day, so a source of support is necessary to cover energy consumption. Obtaining a participation by SFV of 33.8% and the remaining by an electric generator [18].

As photovoltaic solar energy is an intermittent energy due to its energy availability, it is complemented with other sources of electrical energy. A study carried out in Baja California, Mexico, brings together two intermittent technologies such as SFV and wind technology, and complements it together with a natural gas generator that will come into operation at times when irradiation and speed are not available. enough wind to generate enough electricity from the load to be supplied [19].

The cost of supplying the energy demand of a home only with an unconventional technology cannot compete with the electrical network system since having a discontinuous generation, it is necessary to oversize and store the excess electricity generation to cover when not the primary energy is available. Moreno mentions that hybrid generation increases the use of each technology and by not having extra charges suchas transmission, this alternative to supply electricity to non-electrified areas becomes more competitive [20].

The photovoltaic energy systems installed in the residential sector for energy self-consumption present both technical and economic feasibility due to factors such as the useful life of up to 25 years. It also helps to alleviate the energy demand of this sector as presented in the research. Potential effect on the energetic matrix of Honduras with the installation of residential photovoltaic generators for self-consumption [21].

V. Conclusion

The technical and economic feasibility of a solar photovoltaic-biomass hybrid system was determined to meet the demand for power and electrical energy consumption of the home and coffee mill for a coffee producer.

The solar radiation potential was determined with data obtained from RETScreen, corresponding to 5.06 kWh/m^2/day. The total final organic resource available is equivalent to 200 kg.

The actual consumption load profile was carried out, the consumption was determined for both the cutting season and the non-cutting season, which was 1.04 kW and 9.43 kWh and 0.34 kW and 7.16 kWh correspondingly.

The hybrid solar photovoltaic-biomass scenario met all the parameters, both technical and economic. The hybrid system generated 4.05 kWh per day from the photovoltaic solar system and 5.65 kWh, thus supplying the highest consumption of the year. The scenario that presented a higher economic feasibility is the solar photovoltaic-biomass hybrid system, whichobtained a lower levelized cost of electricity than the solar photovoltaic system, $ 0.09 /kWh and $ 0.11 /kWh, respectively.

The system to be installed to supply the energy consumption of the house and coffee processing is the hybrid system that has three 400 W photovoltaic modules, a 2,500 W inverter, two 20 Ah batteries and a charge regulator of a charge current nominal 100 A, occupying an area of 5.4 m^2 by part of the photovoltaic solar system. The biomass system covers an area of 21.26 m^2, it consists of a roll width of three meters, a water and hydrogen sulfide trap to purify the gas, several accessories for the conduction of biogas and the 1.5 kW generator.

The economic advantage presented by the implementation of any of the scenarios with technical feasibility is that the levelized cost of electricity (LCOE) is lower than the current electricity rate in Honduras, corresponding to $ 0.20 /kWh for July 2021. The LCOE of the solar photovoltaic-biomass hybrid scenario was $ 0.09 /kWh.

VI. Author's Contribution

The authors participated in data collection, literature review, data analysis, and writing of the final manuscript.

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IV. Conflicts of Interest

The authors declare no conflict of interest.

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