Design of a Renewable Energy Generation System for an Electric Craft Brewery

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Abstract*– One of the paradigms in Colombia is that Renewable Energies (RE) are expensive and only works on illumination and low powers, this work show that the private sector can invest in RE to feed its processes to medium loads, to carry this out, the innovation has to be in industrial processes too. This work innovate with a pioneer electric brewery plant in Colombia that is fed with a micro-red of generation of hybrid ER interconnected to the network; The Colombian legislation already allows this and it proves the feasibility from two optics, the technique modeling and simulating the electrical scheme in Matlab to comply with the electrical requirements; And from the financial point of view, with the HOMER PRO software, which simulates the electrical system as a viable hybrid generation plant. On the other hand, these projects, both the brewery and the hybrid energy are projected to generate seven direct and five indirect jobs of quality, with qualified and unqualified personnel, vulnerable population, and single mother's head of household. The two corners of the project contribute to employment generation and technological innovation.

I. INTRODUCTION (HEADING 1)

Colombia must adapt its energy matrix by implementing ER and hybrid systems in non-interconnected areas (ZNI) and in cities, the private sector must have incentives to develop this type of projects, it must be robust, technically functional and financially viable, the ER in Colombia are scarce and of shallow diffusion [1], that is why this project aims to demonstrate that it is possible to adapt ER to the Colombian energy matrix, to contribute to the generation of quality employment, technological innovation and reduction of GHG (Greenhouse gas emissions) [2].

The project works over an industrial application of cyclic consumption with medium power to be fed with a microgrid, is an electric beer craft plant of 18 kWp, of cyclical consumption, plants of this type are also innovative in Colombia [3], this process connects with clean energies, the hardware is dimensioned, the solar resource information is generated at the assembly site, the hybrid system is modeled using MATLAB for model simulation [4] and HOMER to demonstrate its viability [5], and demonstrate that if it is possible to integrate ER micro-systems in medium loads production systems with private capital, to innovate and contribute to development of the Colombian energy matrix, to generate quality employment with the production of beer craft with 7 direct jobs, where emphasizes the vulnerable population, 2 single mothers, one of them belonging to the black population from Choco, contribute to agricultural development with the constant purchase of domestic barley and wheat for a projected production of 300 liters per day y [6]. The capital flow generated by this project, allows to develop the innovation with micro red of generation dedicated for cyclic consumption; The purpose is to contribute from the academy in a first phase and from the productive sector in a second phase to the Colombian technological development, to the energy adaptation to the needs of the 21st century [7], and to innovation in the production of high quality craft beers.

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II. SOLAR RESOURCE AND GENERATED POWER CALCULATION

Site location and data acquisition of solar radiation and temperature through HOMER:

Cra. 2a #18a-06, Bogotá, Colombia (4°36.1'N , 74°4.1'W)

04° 36' 05.75" N 74° 04' 07.42" W

4°36'N 74°4'W

(UTC-05:00) Bogota, Lima, Quito

Figure 1. *Aerial view of project site*

DESIGN

SOLAR GHI RESOURCE

Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Library:

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

Month	Clearness Index	Daily Radiation (kWh/m²/day)
January	0.509	4.860
February	0.481	4.830
March	0.471	4.910
April	0.448	4.650
May	0.470	4.720
June	0.494	4.830
July	0.507	5.000
August	0.498	5.070
September	0.486	5.030
October	0.465	4.700
November	0.487	4.690
December	0.536	5.010

Annual Average (kWh/m²/day): 4.86

Scaled Annual Average (kWh/m²/day): 4.86

Figure 2. *Monthly average solar irradiance*

With this data the daily load is dimensioned according to the consumption cycles of the micro plant and with this information the design of the panels, batteries, inverter and power transfer controllers is designed, as follows:

III. SIZING OF THE HYBRID SYSTEM

According to the energy consumed in the production cycle for 80 gallons, the number of panels is calculated, with an average solar brightness of 4 hours and a half daily, and efficiencies of 0.9% in inverter and load regulator, according to the following equations [8]:

Variable	**Value**	**Un**
Regulator Performance Nreg	0,9	%
Inverter Performance Ninv	0,9	%
Total Power AC EAC	46000	W
Total Daily Consumption ET:		
$E_T = \frac{E_{DC}}{\eta_{reg}} + \frac{E_{CA}}{\eta_{reg} * \eta_{inv}}$	***56.79***	KWh
Generated Power		
HBS Low Month:	***4,5***	h/m
$P_{Gen} = 1,2 * \frac{E_T}{HBS}$	***15.144***	Kw
Canadian Solar CS6X 310P		
Rated Voltage of the Installation Vn	220	Vdc
Rated Voltage of the panels Vm	36,4	V
Number of serial branches		
$N_s = \frac{V_n}{V_m}$	6,04 $\cong$ 7	
Number of Parallel Branches		
$N_p = \frac{P_{GEN}}{P_m * N_S}$	6,62 $\cong$ 7	
Total Number of Panels:		
$N_T = N_S * N_P$	***49,00***	
Total Area Panels	**94,02**	**m2**
Total Price	**$60.264.000**	**Col**

Calculations are made with the Canadian Solar panel model ***CS6X 310P***.

- Battery Nominal Parameters

Average Daily Consumption = $E_T = 47896,7\ W$

Autonomy (A): as of100h,

C_{100} = 5h = 0,2083 days

Available Capacity (Useful) of the battery field:C_μ:

$C_\mu = 1,1 * E_T * A(Wh)$=$C_\mu = 10974,5\ Wh$

Over Rated Voltage of Installation:

$C_\mu = \frac{1,1*E_T*A(h)}{V_n}$=$C_\mu = 49,8\ Ah$

Rated capacity C_n:

$C_n = \frac{C_u}{PD_{max}} = \frac{1,1*E_T*A}{PD_{max}*V_n}\ (A_h)$=$C_n = 166,3\ Ah$

The number of batteries depends on the ***C_{100}*** given by the manufacturer and is given by the ratio [8]:

$$No\ of\ Batteries = \frac{C_n}{C_{100}}$$

They relate the Batteries that supply National suppliers in their web pages:

Table 1. *Calculation of the Number Batteries Ref: MTI2850*

Variable	**Value**	**Units**
Total Daily Consumption ET:	56.79	KWh
Rated voltage of the installation Vn	220	vdc
Autonomy (A)	0,2083	day
Available Capacity (Useful) of the battery field (Cμ)		
$C_\mu = \frac{1,1 * E_T * A}{V_n}(A_h)$	**56,79**	Ah
Nominal Capacity Cn:		
Maximum Allowable Discharge Depth *PDMAX: 0,3%*		
$C_n = \frac{C_\mu}{PD_{max}} = \frac{1,1 * E_T * A}{PD_{max} * V_n}(A_h)$	**189,3**	Ah
AGM Batteries 12VDC-88AH MTEK MT12850HR		
Capacity in Amps	88	Ah
Voltage	*12*	Vdc
Total Batt number	*21*	
Total Weight	**565**	Kg
Total Price	**15.753.941**	$

- Nominal Regulator Parameters

According to the selected batteries, the characteristics of nominal voltage and nominal current [8] are described:

Nominal input voltage Vn = 220v.

Rated output voltage Vbat = 12v.

For the current the sum of short circuit currents of the parallel panels [7]

$$i_{reg} = 1,25 * \sum_{i=1} i_{scr}$$

Where ***iscr*** is the short circuit current; for the case of the Panel ***CS6X 310P*** is:

$i_{scr} = 9,08A$ ∴ 25% reserve for the number of parallel panels that are 7.

$i_{reg} = 1,25 * 7 * 9,08A$

$i_{reg} = 79,45\ A$

MPPT regulators that meet specifications and are obtained in the local market are evaluated:

Table 2. *Calculation MPPT controller Ref: MTI2850*

XANTREX C60 CHARGE CONTROLLER 60A		
Rated Current Regulator	*60*	A
Voltage Configuration	*12 y 24*	Vdc
Total Regulators	**1,3242** $\cong$ 2	
Total Price	**$ 990.000**	COP

- INVERTER NOMINAL PARAMETERS

Since there are no loads of two or more tanks simultaneously, the maximum power is 18Kw, which is the maximum power consumed by the heat resistance of each tank. With a safety margin of 10% [8]:

$$P_{inv} = 1{,}1 * \sum_{i=1} P_{Tot}$$

$$\boldsymbol{P_{inv} = 19{,}8\ Kw \cong 20\ Kw}$$

It must be full-wave three-phase at an output voltage AC 220, which is the input voltage of the resistors according to manufactures. The inverter must be on-grid, or with the ability to synchronize to the Bogota power grid.

Table 3. *Inverter Calculation*

Inverter The Sunny Boy 7,000 WATT GRID-TIE INVERTER		
Calculated Inverter Power		
$P_{inv} = 1{,}2 * \sum_{i=1} P_T$	**20**	Kw
Efficiency	*97,0*	%
Power AC	**18**	Kw
Max. input Current 208 Vac	*30*	A
DC nominal voltage	*310*	V
Frequency	**60**	Hz
Number of Inverters	***3***	
Total Price	***22.945.714***	$

IV. MODELING AND SIMULATION IN MATLAB

Using the Matlab tools, the voltage, power and current characterization of the final arrangement of 7 panels in series and 7 panels in parallel is displayed for 25 ° C and 45 ° C [4].

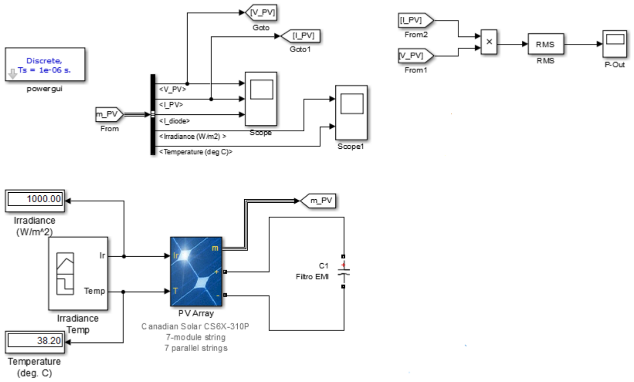


Figure 3. *PV modeling and simulation*

Variables [9]:

Id = Diode current (A)

Vd = Diode voltage (V) = 0.4v

Io = Diode saturation current (A) = 9.7112 e ^ (- 10)

NI = ideal diode factor, number close to unit = 1,0579

K = Boltzmann constant = 1.3806e (-23) JK-1

Q = Electron load = 1.6022e ^ (- 19) Coulomb

T = solar cell temperature = 25 ℃

Ncell = Number of cells in series = 7

Total Voltage:

$$V_T = \frac{kT}{q} * nI * Ncell$$

$$V_T = \frac{(1.3806e^{-23}\ JK^{-1})(25°C)}{1.6022e^{-19}} * 1{,}0579 * 7V_T = 15{,}952\ mvl$$

$$V_T = \frac{(1.3806e^{-23}\ JK^{-1})(25°C)}{1.6022e^{-19}} * 1{,}0579 * 7V_T = 15{,}952\ mv$$

Diode Current Id:

$$I_d = I_o\left[e\left(\frac{V_d}{V_T}\right) - 1\right]$$

$$I_d = 75.3884\ A$$

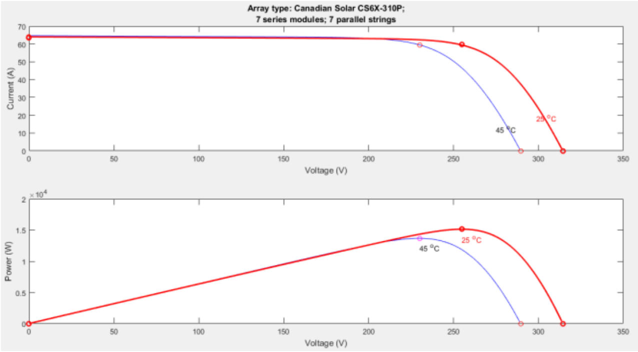


Figure 4. *Characterization Canadian Solar 7X7 PV Array*

- **Calculations of current cyclic loads**

$V_{L-N} * \sqrt{3} = V_{L-L};\ 127\ Vac * \sqrt{3}\ \approx 220\ Vac$ [22]

The current-per-stage calculations according to the loads are:

- *Hot Water Tank:*

$$V_{in} = 220\ V$$

$$P_{Load} = 12Kw$$

$$P_{Load} = V_{in} * I_{TAC}$$

$$I_{TAC} = \frac{P_{Load}}{V_{in}} = \frac{12000W}{220\ V}$$

$$I_{TAC} = 54{,}54\ A$$

In the process, the tank remains on for one hour at Itac=54,54 Ah.

- *Maceration Tank:*

$V_{in} = 220V$

$P_{Load} = 6Kw$

$I_{TM} = 27{,}27\ A$

- *Boil tank:*

$V_{in} = 220V$

$P_{Load} = 18Kw$

$I_{TM} = 81{,}81\ A$

Total Current of consumption cycle:

$$I_{Total} = I_{TAC} + I_{TM} + I_{TM}$$

$$\boldsymbol{I_{Total} = 163{,}07\ A}$$

- BATTERY CHARGER MODEL

The minimum input voltage is used to drive the maxim current [12].

$$D = \frac{V_{out} + V_D}{V_{in} + V_{out} + V_D}$$

Where:

$V_{in} = 220\ V_{DC}$,$V_{out} = 500\ V_{DC}$

$V_D = 0{,}5\ V_{DC}$ $\mathbf{D = 0,7064}$

- **Inductor**

$$L = \frac{V_{in} * D}{\Delta I_{outmax} * f_S}$$

Where:

$V_{in} = 220\ V_{DC}$, $V_{out} = 500\ V_{DC}$

$\Delta I_{outmax} = 0{,}5\ A$, $f_S = 50000\ H_z$

$\mathbf{L = 5,877e^{-3}\ H}$

In this model, the battery starts at 20% load; the output stage of the PV array must go with a DC-DC converter generally type Boost, in this case it simulates and models a much more efficient SEPIC [24].

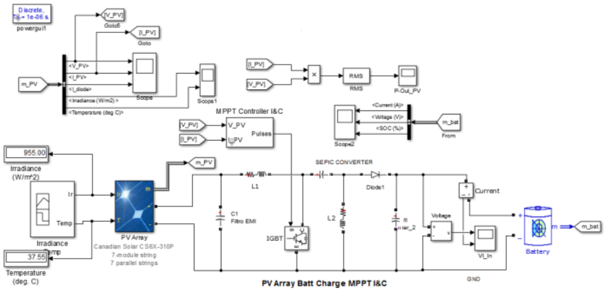


Figure 5. *Modeling and simulation Battery charging stage*

The response of this simulated stage is shown below [10].

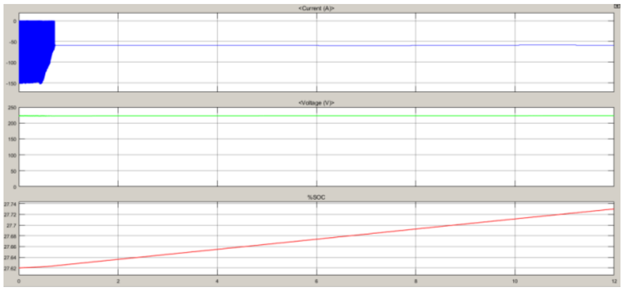


Figure 6. *Battery status: current, voltage and charge state % SOC*

An increase of 0.12v in 12s. Then the stage from the battery to the load is simulated, in this case without the interconnected grid [10].

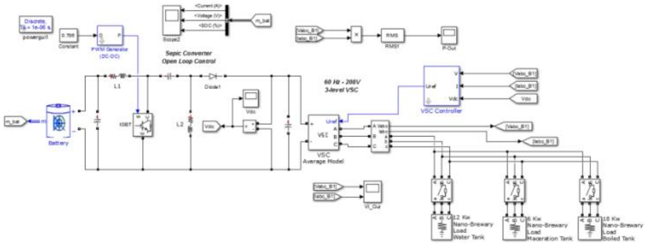


Figure 7. *Modeling and simulation Battery charging stage*

Output response:

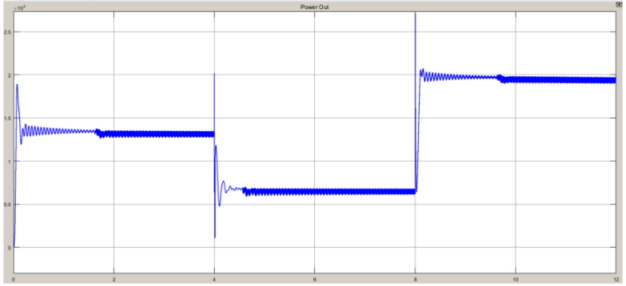


Figure 8. *Output Power of Battery - Inverter – Charge stage*

Clearly it is observed as the output power has the level sufficient to supply the requirements of each tank in each stage. Finally, the generation stage is simulated interconnected to the grid, in this case with bypass, network only and PV array with cyclic loads, without batteries [17]:

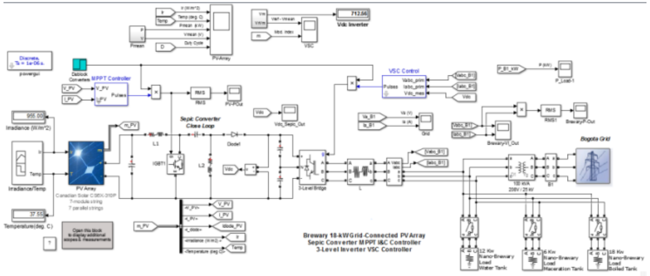


Figure 9. *Modeling and simulation Interconnected generation stage with cyclic loads.*

The output response of the model:

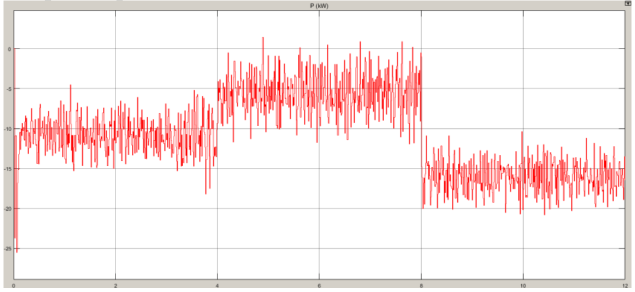


Figure 10. *Output Power at Loads, On-Grid Cycle.*

Current and mains voltage meet the requirements:

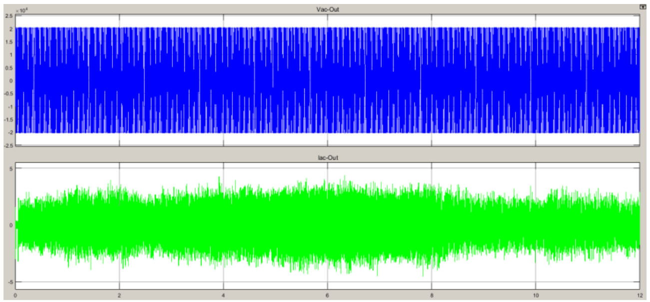


Figure 11. *Current and Voltage on the load.*

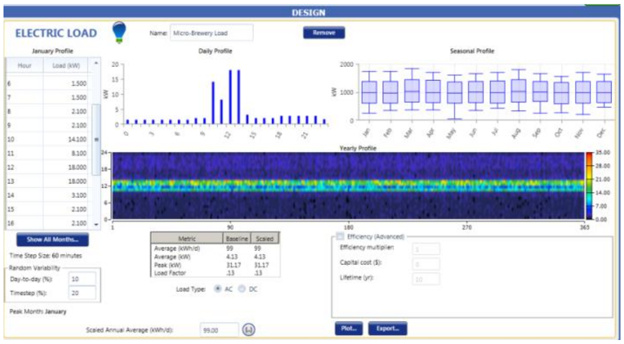
The simulations of the models in stages, indicates that the system responds to the load requirements [16].

In the next chapter we will analyze the model with the HOMER PROFFESIONAL tool.

V. SIMULATION IN HOMER

The tool simulates the possible viable combinations of the sources programmed by the user, this being his main function; Then there is the optimization, the user defines the criteria of the energy system and HOMER helps to optimize the economic model of the system, minimizing where possible the use of fossil sources [].

To improve financial performance, additional and additional loads are added to the beer production facility, which includes refrigeration and lighting.



Name: Micro-Brewery Load

Hour	Load (kW)
6	1.500
7	1.500
8	2.100
9	2.100
10	14.100
11	8.100
12	18.000
13	18.000
14	3.100
15	2.100
16	2.100

Time Step Size: 60 minutes

Random Variability

Day-to-day (%): 10

Timestep (%): 20

Peak Month: January

Metric	Baseline	Scaled
Average (kWh/d)	99	99
Average (kW)	4.13	4.13
Peak (kW)	31.17	31.17
Load Factor	.13	.13

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)

Efficiency multiplier: 1

Capital cost ($): 0

Lifetime (yr): 10

Scaled Annual Average (kWh/d): 99.00

Figure 12. *Extended consumption with neighboring applications.*

Then choose sources and load:

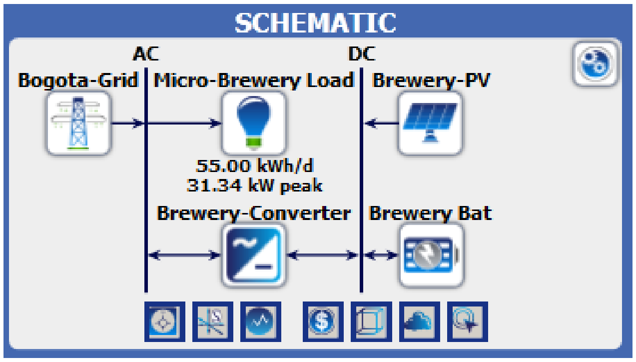


Figure 13. *Extended consumption with surrounding applications.*

There is an increase in the cases of optimization and an effective reduction of the cost of COE energy that happens to have a value of USD 0.17 (503 COP) per kilowatt, less to the first case, and much less to the case of conventional energy that is USD 0.191 (562 COP), graphs are generated where you can compare variables of the energy system, such as the PV system cost of investment vs the cost of energy:

In this case indicates that to have a cost of ***USD 0.175*** per Kw requires an investment of about ***USD 20,000 (59,235,411 COP)***. The actual costs are close to those proposed by HOMER, and are U***SD 25,757 (75,756,000 COP)***. A 10-year investment is projected and the basic financial variables are calculated:

Table 4. *Calculation of Financial Variable (COP)*

		Investment	**-75756000**
		Saving $/year	10397030
TIR 15 years			**6,21%**
Net Present Value **NPV**			**$50.251.211**
Cost Benefit Ratio **R B/C**			**0,6633**

Additional information provided by HOMER:

The CO_2 reduction for production of 18KWp is about $9000\ KgCO_2$. The graph also indicates that if zero CO_2 emissions are required, the system must produce $30000\ Kwh$ in the PV generation system. The CO_2 data is corroborated by the UPME environmental calculator [13], as shown in the following Table

Table 5. *Emissions CO2 environmental calculator UPME*

Grid Energy Emissions	
Total CO2 emissions per 300 liters:	9.154 KgCO2
Volume of gas burned / m Gas burned:	21.9 m /m
CO2 Emission Factors:	646862251 KgCO2/TJ
	: 5.5792 KgCO2/m

According to statistics generated by HOMERO the hybrid system is financially viable and reduces environmental impact.

VI. GENERATION OF EMPLOYMENT AND SOCIAL IMPACT

Every ER project must be strongly linked to the social component, to whom it benefits and how [7]; The high investments have to be justified, the reduction of GHG emissions must justify, and the generation of employment and to which populations it impacts [15]. In this case the craft beer project generates the following jobs:

Table 6. *Jobs and salary(COP)*

Position	Salary
Manager	$ 1.715.124,00
Commercial.	$ 985.415,92

Certified Public Accountant	$ 400.000,00
Beer master	$ 750.000,00
Operating Assistant	$ 360.000,00
Maintenance technician	$ 450.000,00
Food technician	$ 450.000,00
Total annual salary:	***$50.780.231,00***

And the projection of beer sales in the first year according to marketing study and that supports the investment of the ER system:

Table 7. *Projection of beer sales in the year1.*

	Un.	**Year: 1**
Macroeconomic Variables		
Inflation	%	4,40%
Devaluation	%	4,40%
IPP	%	2,71%
GDP growth	%	2,60%
DTF T.A.	%	6,54%
Sales, Costs and Expenses		
Product Price		
Price Beer in Barrel of 20 Lt	$ / u.	300.000
Price Beer in Bottle of 330 ml	$ / u.	3.800
Price Beer in Bottle of 330 ml Custom	$ / u.	4.233
Units Sold by Product		
Und Beer in 20L Barrel	un.	135
Und Beer in a Bottle of 330ml	un.	11.118
Und Beer in a Bottle of 330 ml Custom	un.	12.724
Total sales		
Customer Service	$	136.609.092
Unit Costs Raw Material		
Cost Raw Material Beer in Barrel of 20 Lt	$ / u	67.019
Cost Raw Material Beer in Bottle of 330 ml	$ / u	974
Cost Raw Material Beer in a Bottle of 330 ml make up	$ / u	1.419
Unitary Labor Cost		
Cost Manpower Beer in Barrel of 20 Lt	$ / u.	895
Labor Cost Beer in a Bottle of 330 ml	$ / u.	45
Cost of workmanship Beer in 330 ml bottle Maquiladora	$ / u.	45
Unitary Variable Costs		
Raw material (Average Cost)	$ / u.	1.582,0
Labor (Average Cost)	$ / u.	49,8
Raw material y M.O.	$ / u.	1.631,8
Production Costs Inventories		
Raw material	$	37.931.853
Workforce	$	1.193.715
Raw Material and work force	$	39.125.568
Depreciation	$	5.948.097
Total	$	45.073.665
Gross margin	$	67,01%
Operational expenses		
Selling expenses	$	5.850.000
Administration Expenses	$	70.206.169
Total spends	$	76.056.169

Table 8. *Financial Decision Criteria.*

Decision Criteria	
Minimum rate of return to which the entrepreneur aspires	**18%**
IRR (Internal Rate of Return)	**20,27%**
NPV (net present value)	**8.914.75**
PRI (Period of recovery of the investment)	**2,78**
Duration of the unproductive stage of the business (implementation phase) .in months	**3 month**
Initial level of indebtedness of the business, taking into account the resources of the fund to undertake. (AFE / AT)	**83,64%**
Period in which the first expansion is proposed	**17 month**
Period in which the second expansion arises	**37 month**

The table includes some decision criterion variables for the industrial beer production investment.

Finally, the project impacts on the agricultural sector of barley and malts, an activity that grows, generates quality rural employment, the following graph shows the fall in crops of this type:

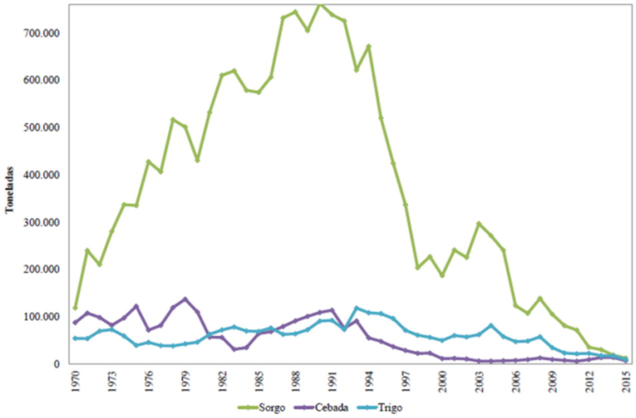


Figure 14. Historical legume production in Colombia.

Source: [20]

It is clear to see that this type of crops can be boosted if the craft beers sector is strengthened in Colombia, contributing to improve conditions in rural sectors of several areas of the country.

VII. CONCLUSIONS

The implementation of renewable energies in Colombia is progressing slowly, private initiatives are minimal [14], there are very few hybrid systems in cities interconnected with the grid, the main sources are hydroelectric and thermoelectric plants that generate significant environmental impacts; This research work demonstrated the technical and financial viability of a hybrid generation system in a cyclical industrial process, in this case an electric beer plant with capacity of 80 Gal and 18 Kwp of consumption, pioneer in Colombia, in the center Historic city of Bogota. Modeling and simulation with MATLAB and HOMER PRO software provided knowledge to promote and innovate in the artisan beer and clean energy production industries in Colombia, adapting it to the needs of the 21st century.

In the case of MATLAB models, they are simulated according to existing designs by authors such as [4] and [16], mainly adapted to the load and to the distribution grid of Codensa [17]. The results show that the electric variables respond to the requirements of the loads, the models simulate medium loads, and they must be simulated by blocks; One of the challenges was to adapt the different controllers to a more demanding load, an advantage is the resistive nature of the load, since additional phenomena to be taken into account in case of inductive or other loads are avoided; In terms of limitations, it was not possible to simulate models with a broad time base, due to computational capacity.

This work is focused on an SME (Small and medium businesses) that connects innovative productive projects with RE, each branch generates quality employment, in the case of craft beer, there is a brewery teacher, assistants, food technicians, electricians, commercial advisers, publicists; Also impacts on agricultural development, with the cultivation of quality national barley and malts, with a cluster of craft brewers, can increase their production even by replacing illicit crops in vulnerable regions [18]; Also innovates in the process of brewing, an example is the state of California of the USA where craft beers generate capital [19]. The development and future implementation of micro grid, provides knowledge to adapt models with cyclical loads designed according to cyclical production, provides viable financial figures to support the investment of microred, the ER project generates indirect employment. The RE sector in other countries generates jobs and moves emerging economies [18]. The contribution of HOMER is important, the tool has many other additional functions that are not explored in this work, however it is shown that the tool is useful to financially improve hybrid electric systems, and helps demonstrate the environmental advantages, more now International geopolitics threatens to reverse progress on environmental issues such as the COP XXI agreement [7].

ACKNOWLEDGMENT

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