ORIGINAL ARTICLE

Energy Sustainability Based on the Implementation of Renewable Energies in Pig Farms: Case Granja "El Guayabal"

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Sostenibilidad energética basada en la implementación de energías renovables en centros porcinos: caso Granja "El Guayabal"

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ABSTRACT: The present investigation was carried out with the objective of establishing the foundations to determine energy sustainability based on the implementation of Renewable Energy Sources (FRE) in the pig center of "El Guayabal" farm. Aspects such as characteristics of the productive scenario, meteorological data of the place, energy demand and possible technological applications based on the use of the FRE were considered, from which the design of a hybrid system with the implementation of these technologies was elaborated. In it, the management of biomass (biogas), solar thermal energy (solar heaters) and solar photovoltaic (photovoltaic panels) was worked on. It was determined that with the electrical energy produced by using biogas, the demand for electricity is covered by 64.84%. The rest of the electricity demand can be covered with the use of solar photovoltaic and solar thermal energy (20.96 and 14.20%, respectively). When carrying out the analysis of the environmental impact, it was evident that the proposed energy system prevents the emission of 9.41 Teq of CO_2/ year, 7.95 m^3/day of methane into the atmosphere, and the consumption of 4.11 Teq of oil/year. It is also possible to produce 0.13 m^3/day of biofertilizers. It is concluded that the proposal constitutes an alternative to minimize damages to the environment, save conventional energy, reduce costs for electricity and obtain biofertilizers that can be marketed and used in different crops; it also improves the conventional energy scheme taking advantage of the FRE.

***Keywords*:** Renewable Energy Sources, Pig Production, Hybrid Systems.

RESUMEN: Con el objetivo de establecer los fundamentos que posibiliten determinar la sostenibilidad energética basada en la implementación de Fuentes Renovables de Energía (FRE) en el centro porcino de la granja "El Guayabal", se realizó la investigación. Se consideraron aspectos como: características del escenario productivo, datos meteorológicos del lugar, demanda de energía y posibles aplicaciones tecnológicas basadas en el uso de las FRE a partir de las cuales se elaboró el diseño de un sistema híbrido con la implementación de estas tecnologías. En el mismo se trabajó el manejo de la biomasa (biogás), energía solar térmica (calentadores solares) y solar fotovoltaica (paneles fotovoltaicos). Se determinó que con la energía eléctrica producida al utilizar biogás, se cubre la demanda de electricidad en 64,84%. El resto de la demanda de electricidad es posible cubrirla con el uso de la energía solar fotovoltaica y solar térmica (20,96 y 14,20%, respectivamente). Al realizar el análisis del impacto ambiental, se evidencia que se deja de emitir a la atmósfera 9,41 Teq de CO_2/año, 7,95 m^3/día de metano, y de consumir 4,11 Teq de petróleo/año, además es posible producir 0,13 m^3/día de biofertilizantes. Se concluye que la propuesta constituye una alternativa para minimizar los daños al medio ambiente, ahorrar energía convencional, disminuir costos por concepto de electricidad y obtener biofertilizantes que pueden ser comercializados y utilizados en diferentes cultivos, además mejora el esquema energético convencional aprovechándose las FRE.

***Palabras clave*:** fuentes renovables de energía, producción porcina, sistemas híbridos.

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INTRODUCTION

Cuba, in order to shape an energy policy in line with sustainable development, has outlined a series of objectives to increase efficiency and the development of renewable energy sources (FRE). With their use, the energy consumption from fossil fuels can be reduced and the environmental impact can be minimized. The country until 2021 had a consumption of 95.2% of fossil fuel and only 4.8% was of renewable energy. For this reason, it has proposed to transform the energy matrix for the year 2030; projecting an increase of up to 24% based on the implementation and use of FRE, which would lead to a decrease in the use of fossil fuels of up to 76% (ONEI-Cuba, 2022).

In recent years, the country has encouraged the use of FRE in livestock. Among them, solar thermal and photovoltaic energy, wind, biogas and gasification (Morejón-Mesa *et al.*, 2022; Oliva-Merencio & Pereda-Reyes, 2022). As the use of these energies is intermittent, FRE's hybrid systems, in any of their solutions or participation, within comprehensive schemes for environmental waste treatment or energy contribution, constitute a contribution to sustainable development within this agricultural branch (Baena-Morales *et al.*, 2021).

The Agrarian University of Havana (UNAH) has a livestock unit within its facilities: “El Guayabal” farm. Its mission is to contribute to the comprehensive training of Cuban students and those of other nationalities, through direct links with community development, teaching, research, production and extension. In addition to productive activities, teaching and research actions are carried out by students, professors and researchers, which facilitate the creation and application of knowledge in the various areas of production and services that make up the referred farm. Taking into account the above, the objective of the work was to establish the foundations that enable the determination of energy sustainability, based on the implementation of renewable energy sources in the pig unit of "El Guayabal" farm.

MATERIALS AND METHODS

Characterization of "El Guayabal" Farm of the Agrarian University of Havana (UNAH)

"El Guayabal" farm is located in Jamaica Popular's Council, belonging to San José de Las Lajas Municipality. It is also part of the Scientific-Technological Complex of Mayabeque Province. For the development of its activities, it has a global area of 846.6 ha where livestock production programs are mainly developed with 67% of the total areas. The pig program is conceived with 240 growing-fattening pigs per stage, twice a year, with an alternative feeding system that uses, among other things, Cuban silage feed as part of the energy fraction that pigs need for their development and balanced dry feed, to cover the protein they require for their development. The volume of excreta and water mixture was calculated according to the Braun (2013), methodology, which determined the production of fecal feces by category and weight of the animal in metabolism sheds and used pressurized water for cleaning.

Evaluation of the Pig Facility Based on the Use of Renewable Energy Sources

A study was carried out to determine the potentialities of using FRE in the swine unit and the energy consumption and availability they have was taken into consideration. The main FRE studied were photovoltaic and thermal solar energy and biogas, which will be implemented according to the existing energy availability in the area and the potential for introducing any of these sources. A hybrid system will be proposed to take advantage of the potential of each one.

Diagnosis of Energy Demand

An energy balance was carried out to determine the electricity consumption in the unit. The present equipment was taken into consideration. A Professional Clamp Multimeter (Steren) was used to determine the consumption by equipment. The monthly and annual consumption was determined, as well as the economic amount.

Determination of the Design and Construction Parameters of the Biodigester

Main parameters that were taken into account for the calculation of a biogas plant:

1. Digester volume

The formula described by Campos (2011) was applied:

$$V_L = (me + ma) \cdot T_r$$

where: Tr - Retention time (time required by bacteria to degrade organic matter, me-mass of excreta, kg; ma-mass of water, kg. According to Lozano *et al.* (2020) biodigesters are generally used to treat concentrated substrates with high solids content that degrade with retention times greater than 21 days. Forty days was used since it works for pigs according to what was reported by Guardado-Chacón *et al.* (2017).

2. Total volume of the biodigester:

To calculate the total volume of the biodigester, the gas storage volume is needed. According to Botero & Preston (1987) and based on the experience in the operation of biodigesters by Barrena-Gurbillón *et al.* (2019) and Ferreira-da Silva *et al.* (2022), the volume

of biogas that will be produced per day will be equal to 25% of the volume of manure: water mixture contained in the biodigester, which is the working volume (Vt).

3. Volumetric organic load:

The volumetric organic load (COV) is the specific volume of degradable biomass for each type or mixture. It was calculated by the following equation:

$$COV = \frac{MV}{V} \cdot t$$

where: VM: volatile mass, kg; BV: biodigester volume, m^3; t: time, days

It was estimated that the dry matter (DM) content is 6% and that of volatile matter is 95%, so the calculation of the volatile matter of the biomass was calculated as follows:

$$VM(kg) = Biomass(t) \cdot DM\% \cdot BV\%$$

4. Amount of methane and sludge produced:

According to FAO (2011) within biogas, methane represents between 55-70% of the volume of gas produced. In this case, 60% was considered. For the calculation of sludge production, 10% of the biodigester volume was used (Moncayo, 2017).

5. Energy potential of the biogas produced

According to Moncayo (2017) the efficiency of biogas when used to generate electricity is 2.2 kWh per m^3.

Methodology for Solar Thermal Energy for Water Heating Use

Water heaters were used in the sanitary filters of the pig center for workers´ sanitization. The demand for water was calculated taking into account that 3 workers work in the unit and according to Bérriz (2007) the demand for hot water used by each of them in the bathroom is approximately 8 L, between 8:00 a.m. and 4:00 p.m., every day. According Bérriz & Álvarez (2008) it was considered that during personal hygiene, the usual temperature is 32 to 43°C.

Procedure for Solar Heaters Use

It was used the methodology proposed by Kumar *et al.* (2019), which follows the following steps:

1. Heaters were oriented towards the south with the help of a compass, for which a space free of shadows was considered.
2. Mean solar irradiation for the region described above.
3. Temperature required by the water to be used.
4. The demand for hot water in the unit was determined.
5. The number of square meters to be used ($A_{unit\text{-}area}$) was determined.
6. Q_U was calculated: Useful energy absorbed by the collector in one hour.
7. The daily efficiency was calculated with Q_U and H_T values for each hour of the day.

Methodology for Photovoltaic Solar Energy (FV) use

With the energy consumption to be supplied, the calculation was made to determine the necessary number of panels. The methodology described by Alonso (2011) and Morejón-Mesa *et al.* (2022) to perform the analysis of energy demand was used. For this, it was necessary to know the total number of animals and the average consumption of drinking water per animal, electricity and water for cleaning and total daily.

Procedure for Determining the Number of Photovoltaic Panels to Install

1. Average solar irradiation for the region. An annual average of 5.4 kWh/ m^2 was assumed, which corresponds to the month with the lowest radiation in Mayabeque Province where the facility is located (INSMET-Cuba, 2021).
2. It was considered that the National Electro-Energy System (NES) has an electrical efficiency of 87%.
3. Photovoltaic modules have 16% efficiency.
4. Taking data (2) and (3) into consideration, the total conversion efficiency was determined.
5. It was used or converted into useful electrical energy (Ee) by taking into account the value of (4) and (1).
6. The number of square meters of modules ($A_{unit\text{-}area}$) that must be assembled.
7. The power of the photovoltaic solar module.
8. Calculation of the number of modules to cover the energy demand according to the following equation:

$$n = (Ee)/(Ee)u$$

Economic-Environmental Evaluation of Renewable Energy Sources Use

To carry out the economic evaluation, the following indicators were determined: Net Present Value (NPV), Internal Rate of Return (IRR), Investment Recovery Period (IRP) and the benefit-cost ratio (B/C). To carry out the environmental evaluation, the following indicators were determined: equivalent tons of oil (Teqp), equivalent tons of CO_2 stopped emitting

(Teq_{CO2}), volume of methane produced (V_{CH4}) and the amount of biofertilizer produced (B_{iop}).

Determination of Energy Sustainability in the Pig Center

The SAFA methodology according to FAO (2015) was used for the evaluation of energy sustainability in the pig center of the Institute of Animal Science. The four dimensions were taken into consideration: 1) Good Governance, 2) Environmental Integrity, 3) Economic Resilience and 4) Social Well-being. For the implementation of the methodology, a series of qualitative criteria were considered, delimited by zoned thresholds that made it possible to weigh the level of sustainability of the production system. A radial graph was made where the situation of the pig center was compared before and after the proposal to include the FRE.

RESULTS AND DISCUSSION

Characterization of the Experimental Area

Table 1 shows the production of excreta and water mixture by animal category that exists in the "El Guayabal" farm. The volumes that are generated justify the use of residual treatments since a problem is solved and it becomes a benefit because energy is generated through biogas and the obtaining of liquid and solid biofertilizers.

Results of the Energy Diagnosis of the Pig Center Studied

After carrying out the energy balance (Table 2), the daily electricity consumption of the installation was obtained. It has two production sheds where the pigs are in the pre-fattening and fattening categories. The water pump can be used both to supply the unit and to irrigate the surrounding areas. The construction of a Vitafert additive according to Elías & Herrera (2011) production plant, for animal feed is planned.

Design and Energy Potential in the Pig Center

The use of biogas improves the economic indicators of a farm, since it generates income from liquid and solid biofertilizer sale. In addition, it can be converted into a source of energy, for cooking food and for generating electricity (Oliva-Merencio & Pereda-Reyes, 2022).If the above is taken into account, the design of a hybrid FRE system with the use of biodigesters is proposed, where the treatment of residuals is prioritized for the productive scenario. Subsequently, the rest of the FRE are used where they are valued as suitable for the scenario and with the aims of supplying the total energy demand and covering the intermittency of each one of them. This allows for a sustainability study that takes into account the economic, environmental and social impact (Cisneros-Ramírez *et al.*, 2021; Kantoğlu & Argun, 2023).

For this, the amounts of biogas and sludge obtained for the production of energy and fertilizer were valued as reported by Hermida-García *et al.* (2020). In a second phase, an estimate is made to determine the potential for generating electricity with other renewable energy sources. In agricultural facilities, the use of biogas should be prioritized taking into account the policies outlined by the Ministerio de Ciencia y Tecnología de Cuba and the negative impact of residuals not properly treated. All this allows the implementation in the pig farm of the hybrid system and fully exploit all natural resources, without harming the environment.

Dimensioning of the Biodigester

For the correct dimensioning, the parameters calculation reflected in Table 3 was required. Based on the determinations shown above, the installation of a

TABLE 1. Production of excreta according to the state of the animal in "El Guayabal" Farm

Category	Number of animals	Mass,kg	Manure production, kg/day	Volume, L/day	kg/day	L/día or kg/day	kg mix /day
					excretes	water	
Pre-fattening	120	20	0,35	1,40	42	168	210
Fattening	120	60	2,30	7	276	840	1 116
Total	**240**				**318**	**1 008**	**1 326**

TABLE 2. Electricity consumption in "El Guayabal" Farm

Equipment	Power, W	Amount	Daily operating time, h/day	Energy, Wh/day
Water pump	5 500	1	5	27 500
Luminaire (rooms)	40	10	12	4 800
Fodder Mill	3 500	1	1	3 500
Electric shower	3 000	1	2,13	6 390
Vitafer plant	1 120	1	2,50	2 800
TOTAL				**61 490**

fixed dome biodigester is proposed. The total volume was taken into account and it was considered that these digesters should not exceed 97 m^3 according to Guardado- Chacón (2007).

Table 4 and Figure 1 show the proposed sizing of the biodigester to be introduced and the design, respectively. Due to the volumes of gas produced, the use of a generator is proposed to obtain electricity to supply part of the unit's demand.

The use of electrical energy produced by biogas covers the demand for electricity in 64.84% for the pig center. Table 5 reflects the evaluation of the hybrid system to be used according to the FRE that have the greatest potential and with the aim of satisfying the total demand for electricity.

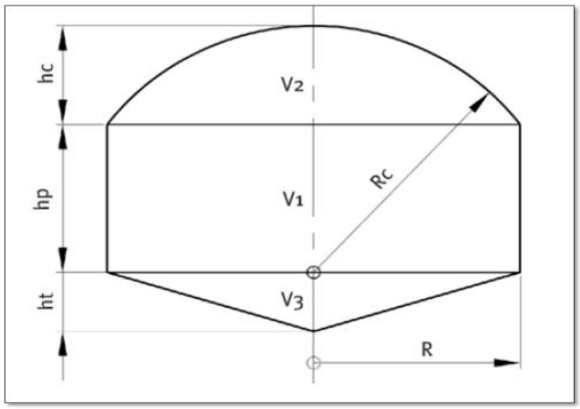

FIGURA 1. Graphic representation of the technology to be introduced in the "El Guayabal" Farm.

Use of Solar Thermal Energy for Water Heating

From the analysis of Table 5, a system of vacuum tube solar heaters for the sanitary filter is proposed, due to the costs and durability of these technologies for water heating. Despite the existence of a generator, close to the biodigester, given the construction characteristics of the unit and the location of the sanitary filter at the other end of the installation; it is feasible to mount vacuum tube solar heaters so that there are no losses of heat. For this, it is necessary to install a 90 L solar heater model Lp47-1510-30 ACF assembled in Cuba according to Pérez-Acosta *et al.* (2017) that meets the need for 48 L/day of hot water. This would guarantee to cover 14.20% of the total demand for electrical energy of the pig center.

Use of Photovoltaic Solar Energy

After carrying out the study and assessing the type of FRE that can be used to guarantee all the electricity demand in the pig farm, it was determined to use photovoltaic solar energy, since solar irradiation is above 5 kWh/ m^2 average for the day. It is decided not to use wind energy because the wind speed is very low (it ranges between 1.3 and 2 m/s) and on the other hand there are obstacles that create turbulence, factors that affect the generation. The use of photovoltaic panels in the "El Guayabal" farm represents 20.96% of the total demand.

Based on these results and taking into consideration that the photovoltaic solar modules, DSM-250 (Policrystalline Solar Panel), assembled in Cuba,

TABLE 3. Parameters calculated for biodigesters in the production scenario

Parameters	Units	Guayabal
Pig waste water generated	m^3/day	1,33
Biodigester Volume	m^3	53,04
Total volumen of the biodigester	m^3	66,30
Amount of the biogas produced	m^3/día	13,26
Volumetric organic load	kgMV/m^3day	1,42
Amount of methane produced	m^3/day	7,95
Amount of sludge produced	t/day	0,13
Electrical energy produced	kWh/day	29,17
Electrical energy produced in the month	kWh/month	875,16
Electrical energy produced in the year	kWh/year	9 626,76
Generator or cogenerator power	kW	1,21

TABLA 4. Dimensions of the biodigester proposed for "El Guayabal" Farm

Linear dimensions	m	Cubic dimensions	m^3
Dome radius	3,33	Dome volume	16,02
Diameter	5,32	Cylinder volume	44,36
Dome height	1,33	Base cone volume	5,91
Cylinder height	2	Total volume	66,29
Base cone height	0,8		

TABLE 5. Assessment of FRE introduction based on the demand for electricity in the scenario

Parameters	Units	El Guayabal
Electric power demand	kWh/ day	44,99
Biogas. Electric energy produced	kWh/ day	29,17
Solar Thermal	kWh/ day	6,39
Solar photovoltaic	kWh/ day	9,43

of 250 W and 1.63 m^2, are taken, it was determined the number of modules to be installed and the power of the system. This can be seen in Table 6. To fully cover the demand with photovoltaic solar energy, 8 modules with a photovoltaic power of 2 kW are needed for the farm.

Determination of the Economic-Environmental Impact of the Proposed Design

For the feasibility analysis of the investment in the "El Guayabal" Farm, the cash flow of the project was calculated for a period of five years. An investment amounting to 757,000 pesos was considered with an additional cost of total assets of 37,850 pesos, adding a total of 794,850 pesos.

The income was estimated from the production of organic fertilizer that is achieved with the installed capacities. Production is estimated at 0.1326 daily tons of organic fertilizer that can have a price of 8,500 pesos/t. With these assumptions, the annual income values are estimated at 371,943 pesos, which will form part of the entity's Statement of Financial Performance.

Variable expenses are minimal and cover the salaries of people in charge of handling and caring for the biodigester, as well as other necessary resources, including those related to the marketing of the final product. Regarding the fixed costs, an amount was determined that allows the annual maintenance of the equipment. The depreciation rate used was 5% per year, which is within the range established by Resolution 701/2015 of the Ministerio de Finanzas y Precios (MFP-Cuba, 2015). The tax rate of 35% was used, which is the one arranged for the payment of taxes on profits in the business sector.

Regarding the investment variables, the Net Present Value (VAN) is positive, which makes it presuppose that the investment is viable and can be accepted. This criterion is reinforced by calculating the Internal Rate of Return (TIR), which is higher than the discount rate (12%) used in Cuba. In other words, the VAN would continue to be positive for a rate that can reach up to 16%. It should be clarified that even if the investment was made with financing provided by the Bank, the maximum rate used for investment financing is 10%.

The investment recovery period is four years, a very positive aspect that corroborates the feasibility of making the investment. To these aspects must be added additional tasks of investment, among which are:

- Fossil fuel consumption is reduced by 4.11 t, with the consequent saving of 83,994.49 pesos.
- 26,835.41 pesos are no longer spent on electricity consumption. According to the M3-A rate RESOLUTION 66/2021) GOC-2021-347-EX26 (2021).
- 9.41 t of CO_2 are not emitted into the environment, which in Cuba does not yet have a direct economic value for the entities, but in the world institutions that manage to reduce these emissions are subsidized with approximate average values between 50 and 83,27 USD/t.

Determination of Sustainability with FRE Hybrid System in the Pig Center

As reflected in Figure 2, it is shown that with the evaluation of the sustainability indicators applied to the pig farm under study, it is possible to implement the FRE. To make decisions, it must be considered from the investment process to the exploitation of the

TABLA 6. Assessment of the photovoltaic solar energy introduction based on the demand for electrical energy of "El Guayabal" Farm

Parameters	Variable and unit	Guayabal
Conversion efficiency	Ƞ	0,14
Average solar irradiation	I; kWh/m^2	5,40
Useful electrical energy	Ee; kWh/m^2day	0,75
Energy consumption	Edìa; kWh/day	9,43
Area occupied by the panels	S_m ^{2}; m^2	13,04
Unit area	$A_{Unit\ area}$;m^2	1,63
Module power	P; W	250
Number of modules	N module	8

same. According to Collazo-Expósito & Granados-Sánchez (2020) and Baena-Morales *et al.* (2021) in the sustainability model three fundamental elements are integrated: economy, society and environment.

With the results shown in the radial graph (Figure 2) it is evident that the solutions applied in the pig center contribute to the sustainability of the production system, solving environmental problems by improving the negative impact on the environment, as well as producing biogas, electricity and biofertilizers, products that increase the income of production schemes.

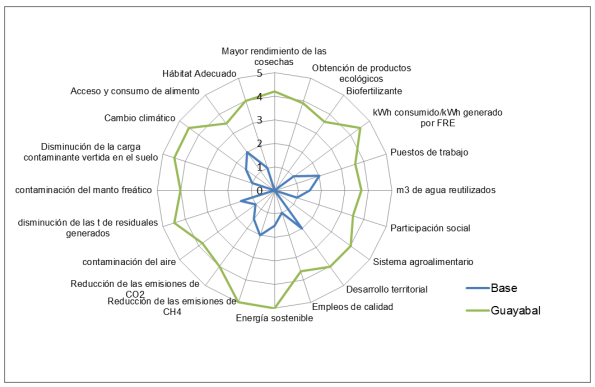

FIGURE 2. Radial graph of sustainability obtained for the base case and for the improved one by installing the hybrid FRE system in the scenario under study.

CONCLUSIONS

The proposal constitutes a sustainable alternative for saving conventional energy with reduced costs for this concept. Damage to the environment is minimized and biofertilizers are obtained that can be marketed and used in different crops. In addition, the energy scheme is improved by taking advantage of FRE's hybrid systems.

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