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Feasibility of a System for Generating Energy from Plant Waste

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Abstract

The rural parish of Ayacucho, located in the province of Manabí, is characterized by significant agricultural activity and the constant generation of plant waste from crops, pruning, and agro-industrial byproducts. In many cases, this waste is wasted or mismanaged, generating environmental and health impacts. Given the need to diversify the local energy matrix and promote sustainable development, the energy use of plant biomass presents itself as a viable alternative to strengthen access to renewable energy in rural areas. The objective was to analyze the technical, economic, and environmental feasibility of implementing an energy generation system using corn cobs in the Ayacucho parish, considering the local availability of biomass, the most appropriate energy conversion technologies, and their potential contribution to the community's energy, environmental, and socioeconomic development. The study concluded that there is significant potential in plant waste to sustain a small- to medium-scale energy generation system. This includes energy production for community self-consumption, reduced dependence on conventional sources, improved agricultural waste management, and decreased pollutant emissions. Additionally, the project could generate social benefits such as local job creation, strengthened technical capacities within the community, and the promotion of a circular economy model adapted to the rural conditions of Manabí.

Contents

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1 Introduction

The depletion of fossil fuel reserves presents a worrying scenario for the electricity generation matrix, since a significant part of the energy demand is supplied by non-renewable energy sources such as coal and oil; being natural resources, the supply of these resources is at permanent risk (Brown et al., 2011).

Biomass was always the first fuel used by humans and was the main fuel before the Industrial Revolution. It was used for cooking, heating, making ceramics, and later, for producing metal and powering steam engines. It was these new uses, and the growing need for more energy in increasingly smaller spaces, that drove the use of coal as an alternative fuel in the mid-18th century (Secretariat of Energy, 2008).

From that moment on, other more intensive energy sources (with higher calorific value) were used, and the use of biomass fell to historic lows, which coincided with the high use of petroleum derivatives and the low prices of these products.

However, biomass continues to play an important role as an energy source in various industrial and domestic applications. Furthermore, its renewable and non-polluting nature, along with its potential to create jobs and revitalize the economies of some rural areas, makes biomass a promising option for the future (Caetano et al., 2017).

The utilization of organic waste of plant or animal origin obtained in natural or industrial processes, called biomass. Due to the plant's photosynthesis process, the energy contained in the biomass is stored as solar energy and subsequently recovered through direct combustion (to obtain heat or electricity) or through the conversion of the matter into biofuels (bioalcohol, biogas, biodiesel, or biooil), mechanical (Martinez, 2014).

Regarding electricity production in Ecuador, the Master Electricity Plan aims to reduce the share of thermoelectric power plants by replacing them with renewable energy sources. In 2016, ARCONEL's annual report states that electricity demand reached 7,606.88 MW. Of this, hydroelectric plants accounted for 58.08%, while thermoelectric plants accounted for 21.18%. Biomass, as an energy source, represented 1.79% of the electricity mix (EP, 2016).

The research offers a fundamental contribution to the environment by using this type of energy from plant waste, which helps control pollution and leads to better utilization. The depletion of non-renewable energy resources (fossil fuels) and the environmental problems they entail have led to a global push for a shift in electricity sources to achieve energy efficiency while maintaining environmental sustainability (Dincer, 1999).

This work aims to support this initiative by developing projects that will enable actions to mitigate the environmental impact generated by the high consumption of energy sources derived from plant waste, thus preventing further global warming, which leads to climate changes that affect the planet's flora and fauna.

2 Materials and Methods

A literature review was carried out; in addition, different operations or procedures were developed to subject the data obtained: classification, registration, tabulation, coding in the survey, including systematization of the information obtained in the surveys.

It is also complemented by the analysis of the data obtained in the research, through logical techniques (induction, deduction, analysis-synthesis), and statistics (descriptive or inferential), which are used to decipher and interpret the information and data collected with methodological rigor. In addition, field research was developed, and it was necessary to collect new data from primary sources to meet the objectives set out in the research.

3 Results and Discussions

The research was developed in the community of San Miguel de "Palo Largo", which belongs to the Ayacucho parish of the Santa Ana canton. It is a community that stands out for its corn harvest, so a survey was carried out among the farmers about the feasibility of using vegetable waste, specifically corn husks, as a source of energy for electricity production.

Corn cobs are the fibrous residue left after corn is shelled. They have a relatively high energy content due to their cellulose and lignin composition, making them suitable for processes such as direct combustion for heat/steam generation, gasification for combustible gas production, and the production of solid (Stronguiló & Chacón, 2015), liquid, or gaseous biofuels.

All forms of biomass have a calorific value, which is expressed as the amount of energy per physical unit (Joules per kilogram). This is the energy released as heat when the biomass is completely burned. The calorific value can be recorded in two different ways: gross and net.

The gross calorific value is defined as the total amount of energy that would be released through combustion, divided by the weight. The net calorific value is the amount of energy available after the evaporation of water from the biomass; that is, it is the amount of energy that can be used, and it is always less than the gross calorific value (Martillo et al., 2019). In practice, relative humidity is the most important factor determining the calorific value. Table 1 shows indicators of the calorific value of biomass (Rojas et al., 2025; Sierra, 2009).

Table 1
Calorific value of some types of biomass

Type of biomass	Gross calorific value(MJ/kg)
Wheat straw	18.94
Cane	18.06
Corn cob	17.90
Rice payment	15.61
Rice hulls	15.58

As can be seen, corn husks are among those with the highest caloric value

Corncob gasification

The results of the first investigations into the parametric studies of corn cob gasification were published in 1972 and 1979 (Lesme et al., 2019). The objective of these investigations was to evaluate the composition and calorific value of the gas produced, which was used as fuel in ovens to heat air, which was subsequently used for drying seeds on farms.

In subsequent years, research on corn cob gasification focused on the use of the gas in internal combustion engines for electricity generation, as well as the development of equilibrium models to evaluate the effects of moisture content on the composition of the generated gas (Lesme et al., 2020).

The results of these studies show that to produce 1 kWh of energy, 1 kg of corn cob is consumed, and that with the increase in the moisture content of the biomass, the amount of CO decreased, contrary to the rest of the CO components.2, H2water vapor increases.

Life cycle of the corn cob

The life cycle analysis of electricity production from corn cobs using gasification and internal combustion engine technologies shows an energy potential of 15.72 GJ/ha per harvest and an electricity generation rate of 115.20 kWh/ton of corn produced. Furthermore, the carbon footprint in terms of greenhouse gas emissions for the evaluated scenarios was 913 kg CO_2.2-eq/t of corn and 797 kg CO2-eq/t of corn, respectively, with a reduction of emissions of 12.7% per harvest.

The residents of the farming community of San Miguel de Palo Largo are involved in the use of residual corn cob biomass as a source of electricity generation. The definition and selection of the sample will depend on the number of people to be benefited; in this case, the sample will be determined by the number of members of the farming community. Thirty-one farmers were selected, who will constitute the statistical population for the research. To obtain the sample, the formula for the population is applied, where the sample was determined according to the application of equation 1.

$$\frac{ZPQN}{WITH^2\ PQ+Yes^2} \quad (1)$$

Where:
N→Population of the universe = 38
P → Probability of occurrence. = 0.50
Q → Probability of non-occurrence. = 0.50
Z → Confidence level. = 99% where Z = 2.58
e → Sampling error = 0.10
n →Sample size

Collection and analysis of survey data

27 men and 4 women were surveyed, revealing that Men are heavily involved in agricultural activities, comprising 95% of the community members. A survey was conducted regarding the quality of electricity service provided by the electric company CNEL EP in the community; the results are shown in Figure 1

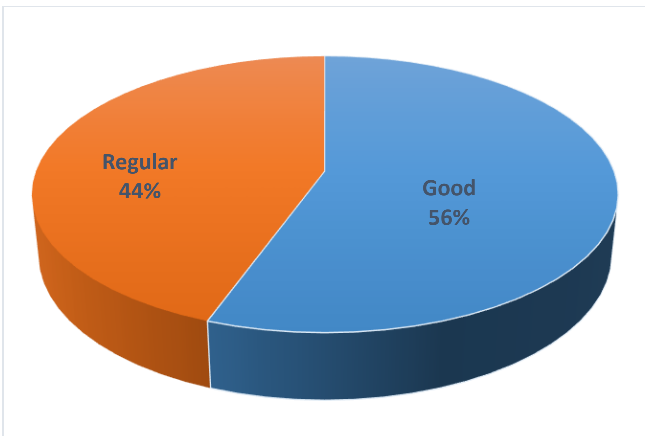

Figure 1. Quality of electricity service provided

The results obtained show that 56% of respondents consider the power quality of the electrical grid to be efficient, and 44% of respondents say they do not have an efficient service. The use of electrical energy in the activities of community members was investigated; the results are shown in Figure 2

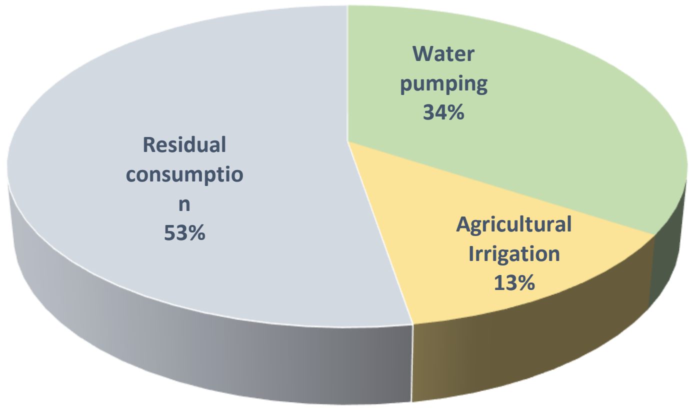

Figure 2. Utilización del suministro de energía eléctrica

The results of the use of electrical energy show that 53% use it for household consumption and 47% for agricultural activities of pumping and irrigation. We asked if you agree with the implementation of renewable resources from residual biomass as sources of electricity generation; the results are shown in Figure 3.

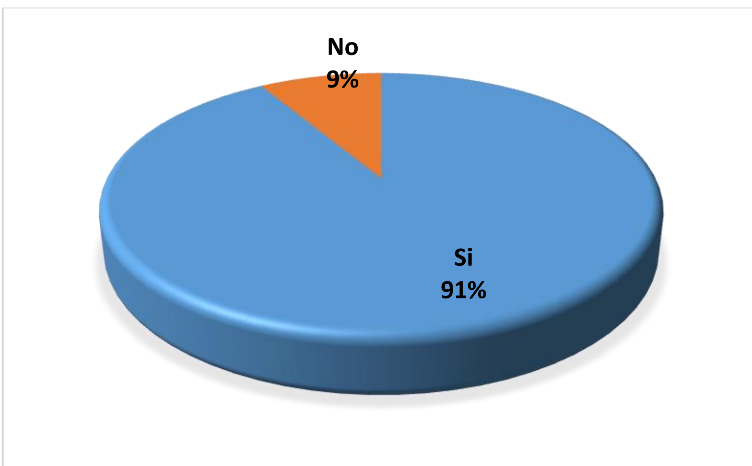

Figure 3. Utilización de la biomasa como fuente de energía

La mayoría de los encuestados (91 %) considera importante el aprovechamiento de los recursos naturales como fuentes de energía eléctrica; solo el 9% no considera la biomasa residual como un recurso para generar electricidad. El tipo de residuos generados en las actividades agrícolas del sector se muestra en la figura 4.

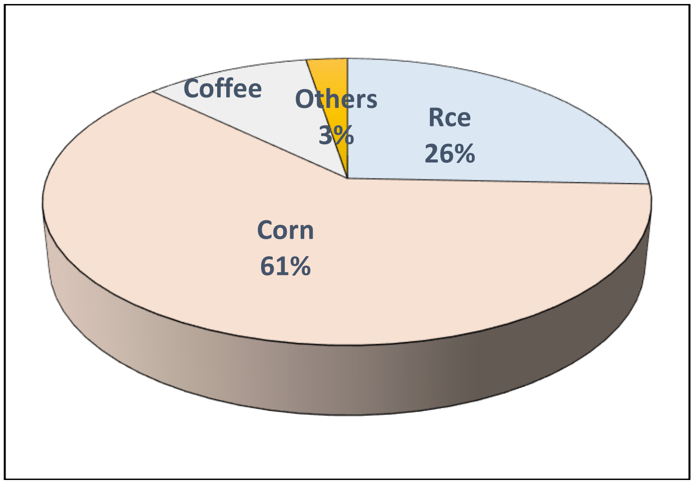

Figure 4. Types of agricultural waste

The types of agricultural waste generated in the community's farming processes were observed; 61% of the waste comes from corn crops, and 39% comes from coffee, rice, and other agricultural plantations (Sierra, 2009). The interest in generating renewable energy as an alternative to the energy supplied by the electric company was questioned.

The residents agree that the use of renewable energy sources should be implemented as an alternative to that supplied by the electric company. The interest in generating electricity by utilizing corn husk waste was investigated, showing how these can replace conventional energy generation in their different applications, as shown in Figure 5.

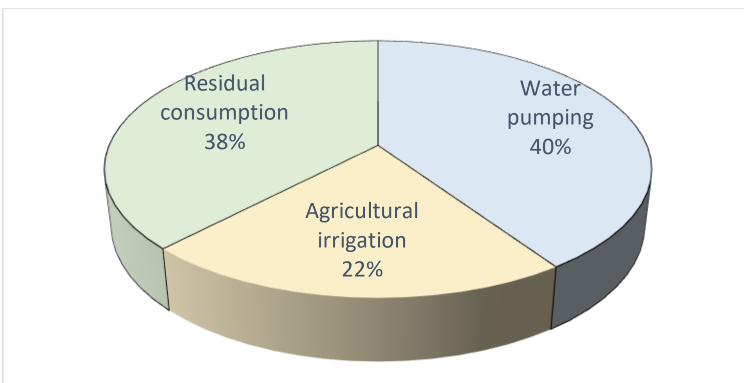

Figure 5. Use of electricity supply through renewable energy sources

Technical feasibility

Corn cobs are an abundant raw material in agricultural areas; their availability is constant and seasonal. The technology used in processes such as boiler combustion, anaerobic digestion, and gasification is well-known, and commercial designs exist. They can be adapted to small and medium scales and can be implemented from rural micro-plants to community systems (Osorio, 2019). It is feasible, but it requires a detailed assessment of the actual availability of the waste, collection logistics, and processing capacity (Patiño, 2014).

Economic Feasibility

It offers potential economic benefits by adding value to agricultural waste because, in many places, the corn cobs that are normally discarded can generate income, it allows for a reduction in energy costs, especially in areas without access to electricity networks or with expensive energy, and it also helps to generate local jobs (Chere-Quiñónez et al., 2022).

Environmental Impact

It has a positive impact by making use of agricultural waste, avoiding open burning, and reducing CO_2 and particulate emissions (Tito, 2022). Corn captures CO_2 as it grows, and when burned, it releases almost the same amount, having a lower net impact than fossil fuels. Provided that emissions control technologies are applied, the environmental impact is favorable compared to fossil fuels or open burning of waste

4 Conclusion

The use of biomass as a source for generating electricity is technically and environmentally feasible, given the good levels of plant waste observed in the community. This would indirectly solve the problem of processing large quantities of waste and generate electricity to compensate for losses caused by the extensive distribution lines throughout the Ayacucho parish, thus improving the quality of service.

The thermochemical characterization of the prepared samples determined that the corn cob has an equilibrium moisture content or internal moisture of 10.5% and a transformable material content greater than 80%, which categorizes the corn cob as a good material for gasification; it is elementally composed of 39.3% Carbon, 4.97% Hydrogen, 0.6% Nitrogen and 47.42% Oxygen, with respect to a dry basis analysis matrix.

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