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Evaluating Sustainable Alternatives for Cocoa Waste Utilization Using the Analytic Hierarchy Process

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Abstract: Cocoa production has emerged as an effective agricultural strategy to reduce conflict in Colombia, transitioning from coca to cocoa cultivation. While this shift has provided economic benefits, it has also resulted in the generation of substantial cocoa by-products. Although there are various alternative methods of utilizing these by-products, many farmers are unaware of them, and others lack the necessary tools to determine which alternative is the best to pursue. This study sought to explore sustainable options for cocoa waste utilization through the application of the Analytic Hierarchy Process (AHP). By employing technological surveillance, viable options for reusing cocoa residues were identified. The AHP results indicate that pellet production is a promising alternative for rural communities. It is also a potential source of energy that could address the community's need for alternative energy sources. Initially, other energy production alternatives were not explored. However, in response to the AHP findings, this study also explored the use of cocoa waste combined with animal manure for energy generation through anaerobic digestion.

Keywords: cocoa waste; renewable energy; Analytic Hierarchy Process; rural development

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1. Introduction

Cocoa production stands out as an agricultural strategy for reducing conflict in Colombia. This has become especially clear since 2010, when the process of replacing coca crops with cocoa began [1]. Cocoa is profitable due to its high global demand, making it a suitable crop to replace illicit crops. This strategy has enabled many Colombian families to generate employment in rural areas and obtain legal economic income. In 2022, cocoa production reached 62,158 tons, with the department of Santander being the largest producer nationally with 36.8%, followed by Arauca with 16.9%, Antioquia with 8.3%, Tolima with 5.8%, Huila with 5.7%, and Nariño with 5.4% [2]. Tolima ranks fourth due to its favorable agroclimatic conditions, which give its crops a competitive advantage, facilitating their access to international markets [3].

Cocoa bean exports decreased from 11,309 tons in 2021 to 5721 tons by November 2022, a drop of 50.5%. However, exports of semi-processed and processed products increased by 21%. These figures reflect how, in recent years, the transformation of cocoa in Colombia has been promoted, generating greater income opportunities for entrepreneurs and the country. Nevertheless, this transformation has also increased the generation of cocoa fruit residues, which require proper disposal or comprehensive utilization for their valorization and the development of new intermediate or final products.

In rural areas, it is common for cocoa pod husks to be used as fertilizer for crops. However, excess husks in the soil can have negative effects, causing diseases in cocoa trees and phytosanitary problems, which can result in significant crop losses due to improper waste management and the proliferation of pests like the cocoa pod borer (CPB) [4]. Inadequate disposal of these residues raises environmental concerns due to the possible spread of diseases and bad odors [5,6]. Despite the existence of valuable applications for agricultural waste that can add significant value, many communities lack sufficient information on how to implement these applications effectively.

In contexts where multiple options are available, the decision-making process becomes intricate due to the diverse criteria that can affect the selection of the best alternative. Social, economic, technological, and environmental considerations often conflict, making it important to balance these competing factors when making decisions [7]. Multi-Criteria Analysis, also known as Multi-Criteria Decision Making (MCDM) or Multi-Criteria Decision Aid (MCDA) methods, addresses the challenge of making decisions that involve multiple criteria. These approaches can accommodate both quantitative and qualitative criteria and are characterized by conflicts among the criteria and challenges in designing or selecting alternatives [8]. In general, Multi-Criteria Decision Making (MCDM) methods are categorized into two main types: Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM). The key difference between these two categories lies in how alternatives are determined within the decision-making process. In MODM, alternatives are not predetermined, while in MADM, alternatives are predetermined and evaluated against a set of attributes [9]. In general, Multi-Criteria Analysis (MCA) is a good tool, particularly in areas and sectors where methods based on a single criterion prove inadequate, and where some impacts cannot be accurately quantified in monetary terms [10,11].

In the field of multi-criteria decision-making (MCDM), various methods are commonly employed, each offering unique advantages and facing specific limitations. Among the most widely used is the Analytic Hierarchy Process (AHP), valued for its ability to decompose complex decisions into a hierarchical structure, facilitating the integration of both qualitative and quantitative criteria [12]. Another popular method is the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which has a straightforward approach to ranking alternatives based on their proximity to an ideal solution [13]. Additionally, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) stands out for its effectiveness in managing outranking problems, making it particularly useful in situations with conflicting criteria. Its visual tools, such as GAIA planes, provide decision-makers with an intuitive means of analyzing alternatives, enhancing the overall decision-making process [14].

Among multi-criteria decision-making (MCDM) methods, the Analytic Hierarchy Process (AHP) has been widely applied in the fields of agroindustry and agriculture, proving to be an important tool for decision-making in complex scenarios involving multiple criteria. In the agroindustrial sector, AHP has been used to optimize supply chain management and to select the most suitable technologies for processing agricultural products. For example, AHP has been employed to prioritize alternative production technologies, considering factors such as cost, efficiency, and environmental impact [15].

Similarly, in the agricultural sector, AHP has been used to support decisions related to crop selection and resource allocation. It has also been applied to determine the most appropriate crop rotation systems, considering soil conditions, water availability, and market demand [16]. Additionally, in the area of sustainable agriculture, AHP has been used to evaluate and prioritize water management strategies that balance economic viability with environmental sustainability [17].

The widespread use of AHP is grounded in its greater flexibility in handling subjective judgments compared to other methods, such as TOPSIS or PROMETHEE. This is a significant feature when working with criteria defined by local communities.

The utilization of cocoa waste can be approached using the AHP methodology, which can help optimize decision-making to maximize environmental, economic, and social benefits. The Analytic Hierarchy Process (AHP) is a structured technique used for organizing and analyzing decisions. AHP helps decision-makers set priorities and make optimal choices by breaking down complex decisions into a series of pairwise comparisons, then