Alpaca Waste Management Model for Improving Fiber Productivity Through the use of Biomass in Andean Highland Communities

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Abstract. In an environment where the international market demands a large amount of fiber, the countries that produce raw material must be prepared to face the fulfillment of exports. However, it must be noted that in majority of the countries, this fiber, such as alpaca, can be found in the mountains at more than 3,000 MASL where frosts are constant and cause deaths. Likewise, if the collection of feces is not adequate, it can represent an infectious focus which, in addition to the deaths, would reduce the productivity of the fiber. Thus, we can say that the main cause is the incipient knowledge of sanitary practices. This document proposes an alpaca waste management model for the generation of biogas for heating alpacas in frost seasons and obtaining biol for the improvement of pastures. The stages in which the project is carried out include infrastructure of the house, connection of house alpaca and system of drainage, biodigester, improvement of pastures. This model was validated by means of a continuous biodigester prototype supplied with alpaca feces and pig biol achieving 1 of biogas.

1. Introduction

At present, Peru is the main exporter of alpaca fiber, accounting for 84% of all alpaca heads worldwide (INEI, 2012). These exports reached US$ 68.3 million between January and November 2017, representing an increase of 110% over the exports in the previous year, according to the Ministry of Foreign Trade and Tourism (Mincetur). Alpaca production is mainly distributed among the Puno, Cusco, and Arequipa regions, with Puno being the largest producer (65.4% of alpaca heads). The situation is favorable for Puno, as it would become the largest supplier of this type of fiber. However, there is deficit not only in the amount of fiber extracted per alpaca but also in terms of quality. This problem is mainly caused by the incipient knowledge of sanitary practices resulting in inadequate breeding conditions for the survival of the species and for fiber. Notably, these conditions occur in times of frost where the alpaca is threatened by abiotic agents such as the weather and biotic agents like accumulated feces within the sheds. To solve this problem, there are several alternatives for the collection and treatment of manure. Therefore, this research article proposes an alpaca waste management model using a combination of environmental stool treatment techniques supported by industrial engineering tools. This creates a sustainable energy system that solves the problem of
collecting feces, formation of infectious foci, and generation of biogas to produce a thermally comfortable and clean environment for alpaca breeding using biomass treatment.

2. State of the art
In literature, several models have been identified to address the causes of the emerging awareness of sanitary practices in raising these camelids.

2.1. Manure Management Techniques
The anaerobic digester system has become one of the most dominant techniques in addressing the issue of manure, decreasing the polluting potential of the excrement, and reducing greenhouse emissions [1]. It contributes to the use of organic energy and maintenance and improvement of the fertilizing value of treated products [2]. Ribeiro [3] applied it in a pig farm in Brazil, which is the fourth largest producer and exporter of pork in the world. To ensure compliance with food safety and climate change mitigation, he used a flare biodigester for energy purposes and to improve composting. Exploiting pig waste helps avoid some types of diseases not only while breeding but also in the quality of life of the animals themselves. This system is based on manure management, which increases the economic viability of the anaerobic biodigester by eliminating the construction of traditional manure storage wells subsequent to farm digestion [4]. This system features a unique design based on manure storage pits that directly feed into the biodigester. Then, the post-digested manure (digestate) is stored on the floors of these pig houses. It was found that the farm collected 75% of all manure produced by reducing solids and carbons [4]. The biogas content consisted of 29% CO2 and 71% CH4. The gas was used to produce 612,504 MJ of electricity during a stable state period of 24 months [4]. The electricity was valued at $11,450 and fulfilled 50.3% of the demand for pig houses and the manure treatment system. Additionally, the pig house design improved the economic viability of this farm [4].

2.2. Structural Design of Recollection Process
Geoffrey Guest [5] and Chavarria [6] mentions the need to move toward a more sustainable food system, which has led to a general increase in the number of life cycle assessments (LCAs). Therefore, his literature [5] seeks to use a detailed comparative LCA in a dairy production farm located in Ontario, Canada, which recently adopted an active composition system that incorporates a solid/liquid separator with screw press before composting in the container, using automatic composting-manure separator technology to determine environmental advantages and disadvantages [7].

Another solution method used by Vermeulen [7], proposes the implementation of dehydration technology by applying DME to use manure as biogas, since the excess of livestock fertilizer generated on a daily basis and the conventional practices are not sufficient for efficient management. This solution for dealing with excessive livestock manure is a novel idea, which would also reduce pollution. The author also determined the risk of fertilizer self-ignition after the dehydration process.

3. Contribution

3.1. Proposed Model
The alpaca waste management (MGRA) model shown in Figure 1 represents the overall project. To develop each stage of the model, a theoretical version is denoted in Figure 2. This model consists of four fundamental phases and a prior phase. The design was created by adapting environmental engineering tools, such as drainage, anaerobic, and heating systems, which were developed using the PDCA methodology and industrial engineering tools. Likewise, a previous stage called Change Management was included in each stage of the model. The MGRA phases in which an adaptive change was generated are detailed below:
3.1.1. Phase 0 Change Management

**Resistance to Change Assessment:** Resistance to change is a key indicator that allows us to assess the level of resistance that the company currently presents. For these purposes, the OCAI method was used because it makes quantifications based on surveys, and the questions are structured by the managers of the organization.

**Training and Awareness:** The main focus of the training is to convey to farmers the relevance of the problem of low fiber productivity in this area and how they can develop responsible breeding that ensures optimal production through a comprehensive waste management system. Therefore, it is essential to secure their support for the development and implementation of the proposal.

**Support Groups:** Support groups are formed at the end of the training. Breeders are selected based on each activity to achieve the set objectives. Likewise, throughout the implementation stage, the trainer will provide 100% support and guide the teams.
Compliance Survey: Measuring the progress of change management will detect the satisfaction level of and rate of resistance to change in employees.

3.1.2. Phase 1 Planning “P1”
Symptom Analysis: The planning stage identified that the productivity of the study site was below average standards. This negative trend is a symptom of the existence of a problem. Subsequently, this trend translates into economic impact reflected in a decrease in income in the region.
Cause Analysis: To identify the root cause, the problem tree is assessed in three large subdivisions, and the main root causes to be resolved are detected.
Hypothesis Formulation: A hypothesis related to the problem found is formulated and the techniques that will resolve it are determined.
Process Standardization: The model processes will be standardized as a working method to serve as an execution guide. To do this, the proposal processes have been mapped, which are analyzed and related to the impact they have on project objectives and customer satisfaction to determine the critical processes. The critical process matrix (MPC) will be applied, along with the process map and flowcharts. This provides an overview of how to manage each process, identify strategic processes and bottlenecks, and understand the importance of each process.

3.1.3. Phase 2 Development “D2–D4”
In this phase, the different systems that allow biomass collection and use are developed using the industrial engineering tools that support the research.
Drainage System: A grid system is proposed along with manure pumping, which avoids surplus digestate storage costs in a housing unit, with a manure storage under the shed. The process begins with the adaptation of the shed (corral) incorporating a storage pit to advantageously collect the stools deposited in the excrement areas located in the center. Once treated, the manure inside the biodigester returns to the pits located in the lower area known as return wells.
Anaerobic System: Biodigesters adapted to the cold are located inside a compact greenhouse with large adobe walls. For the process, it is necessary to take into account the selection of the installation site, considering available spaces and structures, and analyze how to incorporate the system into the sheds. For installation, it will be necessary to consider that the major axis of the digester must be in the direction of east to west, with the greenhouse shed facing the winter sun. In this way, solar radiation can be used.
Heating System: Manure processed under the anaerobic systems serves as fuel for the operation of eight lamps powered by propane or biogas. These are used to provide a thermally comfortable environment for alpacas, which improves the animals’ quality of life.

3.1.4. Phase 3 Analysis of “C5”
The indicators are variables that allow for quantitative or qualitative measurement to support the decision-making process. These indices fulfill specific control functions, which are applied according to the needs of each company. During this stage, indicators for each stage of the model are detailed and identified with a code for traceability. Indicators are named based on the following nomenclature: Indicator (First letter of the stage) (Stage No.) - (Indicator No.) MGRA: Name of the indicator
Training and Awareness Indicators: After completing the training and awareness process, a knowledge test will be applied on each trainee in order to determine whether the necessary knowledge was acquired to execute the project. If the person obtains a result equal to or greater than 13, they will be considered approved.
G0-1MGRA Indicator: % Successful Training Sessions

$$\% \text{Successful Training Sessions} = \frac{\text{# workers with grades higher or equal to 13}}{\text{total # workers}} \times 100$$ (1)

Progress Survey Indicators: This indicator shows how satisfied is the person who trained with the project development. Also, this metric helps diagnose discrepancies within the work group.
G0-2MGRA Indicator: % Satisfactory Progress
% Satisfactory Progress = \frac{\text{Sum of Grades}}{\text{# trainees}} \times 100 \tag{2}

**Drainage Systems:** In the first phase of the development process, manure is collected seeking to compile the largest amount of biomass possible. To determine if the process is successful, the first indicator must be greater than 90%, and the second must be greater than or equal to 3 kg per day per alpaca.

D2-1MGRA Indicator: % Manure Collected

\[
\frac{\text{% Manure Collected}}{\text{Total manure collected (KG)}} \times 100 \tag{3}
\]

**Anaerobic Systems:** The second phase of the development process is the anaerobic system, where the biomass collected through the drainage system is treated. The objective of this phase is to obtain biogas and biol. To determine if the process is successful, the amount of biogas must be greater than or equal to 0.78 m³ per day. Also, temperature of 19–23°C and pH level of 7.06–7.22 should be maintained.

Indicator D3-1MGRA: Biodigester Efficiency

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\frac{\text{% Biodigester Efficiency}}{\text{Total biogas obtained (m³)}} \times 100 \tag{4}
\]

Indicator D3-2MGRA: Average Daily Biodigester Temperature

\[
\frac{\text{Average Daily Biodigester Temperature}}{\text{Sum of Temperatures Recorded} / \text{# Records per Day}} \times 100 \tag{5}
\]

**Heating System:** The objective of this phase is to keep the biogas lamps going for approximately 12 hours so that the alpacas achieve a microclimate ensuring their survival in times of frost. The first indicator (D4-1MGRA) provides the average temperature inside the sheds, which should be maintained at 19°C on average. The second indicator (D4-2MGRA) records the consumption of biogas per hour, which must be at least 0.065 m³ per hour. Finally, the D4-3MGRA indicator provides the biogas pressure in contact with the operation of the lamps. This number, according to literature, should be greater than 28 millibars.

D4-1MGRA Indicator: Average Shed Temperature

\[
\frac{\text{Average Shed Temperature}}{\text{Sum of Temperatures Recorded} / \text{# Records}} \tag{6}
\]

Indicator D4-2MGRA: Biogas Consumption per Hour

\[
\frac{\text{Biogas Consumption per Hour}}{\text{Biogas used in m³} / \text{# hours of operation}} \tag{7}
\]

### 3.1.5. Phase 4 Acting “A6”

This phase consists of assessing unexpected results. Basically, it is called the feedback stage, as in this phase, process improvement opportunities are identified. Likewise, the PDCA cycle allows improvement assessment to continue, returning to the initial stage in search of new problems that require improvement, thus becoming an endless cycle.

### 4. Validation

The research study is conducted in Puno, taking into consideration all the variables such as climate, temperature, latitude, pressure, number of alpacas, and other variables used for model simulation. The alpaca owners are small breeders, meaning ordinary people who do not have a company incorporated; therefore, the project is not focused on one company but on the entire sector.

The validation of the MGRA steps are shown below:
Stage 0: Change Management
In the first stage, employees are trained and sensitized to the problems in the sector and the methodology of the management model. At the same time, support groups and progress surveys are created to guarantee staff satisfaction.

Stage 1: Planning “P1”
With the MPC, there was proof that the processes with the greatest impact on objectives included the heating system, production (anaerobic system), and manure collection. Given that the MGRA is a new proposal, which is not included in the current alpaca fiber value chain, the standardization of the processes within this model has been proposed with support from the process map to visualize the overall flow.

Stage 2: Development “D2–D4”
The experimentation of the anaerobic system prototype was performed in three continuous biodigesters. Owing to this simulation, biogas production was evaluated. The simulation of the operation of the anaerobic system was developed in three buckets of 50 liters each, with an initial load of 60 kg of manure.

Once completed, the data collected on Day 30 found production of 0.3 m3/day, thus giving an optimal result for the project. It is also emphasized that the system will produce biogas with a higher concentration of methane for a longer fermentation time. The results of the most important variables of the experiment are shown in table 1.

Table 1. Results Table

| Variables                        | End       |
|----------------------------------|-----------|
| Biogas obtained (m3)             | 0.3       |
| Lamps on                         | 2         |
| Duration of time lamps on        | 30 min    |

Stage 3: Assessment of “C5” Indicators
At this stage, the techniques implemented to determine if the proposals have positively impacted the root cause of the problem are analyzed. Table 2 shows the results of the indicators determined for the validation of MGRA.

Table 2. Results of Indicators

| Indicator                                | Coding     | Reference level | Results  | Validation     |
|------------------------------------------|------------|-----------------|----------|----------------|
| Percentage of Successful Trainings       | G0-1MGRA  | 90% - 100%      | 90%      | complies       |
| Percentage of Satisfactory Progress     | G0-2MGRA  | 90% - 100%      | 90%      | complies       |
| Percentage of Manure Collected          | D2-1MGRA  | 90% - 100%      | *        |                |
| Percentage of Manure Collected Daily    | D2-2MGRA  | 90 - 150 kg     | *        |                |
| Average Daily Biodigester Efficiency    | D3-1MGRA  | 90% - 100%      | 70%      | does not comply|
| Biogester Temperature                   | D3-2MGRA  | 19 - 23 °C      | 20 °C    | complies       |
| Biodigester pH Level                    | D3-3MGRA  | 7.06 - 7.22     | 7.2      | complies       |
| Average Shed Temperature                | D4-1MGRA  | 19 - 30 °C      | 19 °C    | complies       |
| Biogas Consumption Per Hour             | D4-2MGRA  | 0.0325 - 0.065 m3| 0.060 m3| complies       |
| Biogas Pressure                         | D4-3MGRA  | 20 - 28 millibars| 23 millibars| complies     |
| Ppm of Hydrogen Sulphide                | D4-4MGRA  | 0 ppm           | **       |                |

Stage 4: Acting “A6”
At this stage, the results obtained from the MGRA proposal are assessed. However, another run of the model could not be executed because of it being a real experimentation on a prototype scale.
5. Results

- 90% of the breeders polled agreed with the implementation of the model. This aspect is favorable for better model implementation.
- Training progress of 90% was achieved.
- An efficiency of 70% in the operation of the biodigesters was achieved.
- The biodigesters were maintained at a temperature of 20°C to facilitate decomposition.
- A pH of 7.2 was achieved, which is optimal according to the literature.
- A temperature of 19°C was achieved inside the shed. (The shed was simulated, and the temperature was taken with the lamps switched on for 30 minutes).

6. Conclusions

This research project managed to compare and combine environmental tools using the PDCA methodology and industrial engineering tools within the alpaca waste management (MGRA) model. Additionally, the experimentation of the three prototypes of biodigesters was important in demonstrating the extraction of biogas from alpaca manure. It should be noted that estimated values calculated from literature were considered through drainage system concepts, amount of manure per day, number of total solids, retention time, biodigester volume, and biogas production, among other variables.

The prototype development used an initial mixture of biomass to fill a bucket with 12 kg of alpaca manure and 36 liters of pork boil at a ratio of 1 to 3. In this way, 0.3 m³ of biogas could be obtained per day in a production span of 30 days, which implies that the estimated amount of biogas will be reached (0.78 m³ per day to keep eight lamps switched on for 21 days).

The reduction in alpaca mortality could not be directly validated. However, this could be inferred, as it was possible to integrate a heating system to guarantee a microclimate of 19°C inside the shed. In the same way, manure collection could not be validated either, since it would be necessary to implement the full-scale model. However, the dimensions of the shed were conditioned according to the literature, and a design for the alpacas shed was proposed.

Finally, the project standardized the MGRA processes so that, whenever required, each step can be carried out within the process map and the critical process flowcharts.

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