A TECHNOECONOMICAL FEASIBILITY STUDY OF THE USAGE OF ORGANIC WASTE FROM UNIVERSITY CAFETERIAS FOR THE PRODUCTION OF BIOGAS.

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UNDERGRADUATE PROJECT TO OBTAIN THE BACHERLOR TITLE OF INDUSTRIAL ENGINEERING

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Index

Table Index

Figure Index

Equation Index

ABSTRACT

This project sought to estimate the total waste produced by the university so that its final disposal has a positive use with the objective not only of the impact of the ecological footprint by the university, there is also the possibility of cost savings.

The project looked for similar cases globally as in Latin America with the objective of having a closer idea in the implementation of biodigesters in educational communities, with the clear benefits exposed by these cases it was decided to estimate the amount of organic waste by the university, without However, these were not always separated from inorganic waste, so they could not be counted on all of them.

Once the total amount of waste available from the university was estimated, another degree thesis was used, in which the LBW, SV and CH4 available from these waste were known, with which a little more than 4000 cubic meters was obtained on the year.

Finally, the reduction of the carbon footprint after the estimation of its reductions in tons of CO2 equivalents that reach more than 35% of the carbon footprint.

CONTEXT, JUSTIFICATION AND PROBLEM FORMULATION

There is a growing demand for education in Colombia, and in recent days university admissions and campus sizes have been increasing, resulting in the establishment of more on-campus cafeterias and restaurants. These cafeterias prepared daily lunches for the students or workers of this university, and University ICESI has many such restaurants and cafeterias on campus, which generates a significant stream of organic waste, which included table food waste (i.e. leftover food), as well as food waste generated during meal preparation.

Inside of the university there are plans that disposed these wastes, one part of it is used in composting which is selected, not all waste can be used for this process, such “Aguamasa”, on the other hand in this process, gases with unwanted odors and leachate, are created; however there are certain wastes that cannot be exploited by this method or there are not the adequate suppliers to properly dispose of them, so the university has to pay a provider out of town to come for this waste which is an additional cost that could be decreased.

This waste could be the input of a biodigester which has been used for the production of biogas and fertilized material, Nevertheless, certain conditions and amount of waste must be checked before it can be implemented which would bring three solutions to issues that the university has, which are the reduction of the cost for the use of this waste, a possible reduction of the footprint ecology and the most attractive would be the use of biogas fertilized material adequately within the university for use in laboratories or in the same cafeterias.

OBJECTIVES

General objective

Analyze and evaluate the technical and economic feasibility of biogas production from anaerobic digestion of organic waste generated from the cafeterias and gardening activities at Universidad Icesi.

Product: A feasibility study

Specific objectives.

Identify and estimate organic waste streams at Icesi using university data bases and direct quantification.

Product: Food waste database analysis, Aguamasa quantification report and analysis.

Estimate the potential annual biogas production for identified waste streams at the university using data from previous work, taking into account seasonal variation.

Product: Report estimating biogas production and analysis.

Evaluate economic benefits for implementing a tubular Biodigester technology.

Product: Report estimating cost, benefits and payback for implementing a tubular Biodigesters.

REFERENCE FRAMEWORK

In order to understand the benefits and implications that a biodigester can have in the university, it is necessary to study cases worldwide and also cases much closer to our region, such as Latin American cases. We sought to find the best approximation to compare it with this specific case.

Cases USA

As a developing country Colombia has to adapted and look around the several cases in universities several universities resolved their issues or how can the food waste can be disposed, an expel of this and how the institution have adopted AD as a way to reduce food waste disposal and fossil fuel consumption. The University of Wisconsin at Oshkosh operates a dry AD process that utilizes organic waste materials derived from agricultural plant waste, yard waste, and food waste generated on campus. The estimated feedstock supply is 6000 tons of organic waste and the net energy generation is approximately 6,400,000 kWh per year. This amount of electricity is expected to power up to 10 percent of the university's energy requirement (University of Wisconsin at Oshkosh, 2014) bunt not only this university focus on the AD process before of them The Ohio State University (2012) initiated the construction of a dry AD process in 2012 with a processing capacity of 30,000 tons of agricultural and food waste per year. The system is expected to produce 7800 MWh of electricity every year.

The food waste generation at University of Cincinnati (UC) was estimated to be 146 tons per year. (Møller et al,2009) reported biogas production from food waste to be 130 m3 per ton, and the biogas typically consists of 65% methane and 35% of carbon dioxide (v/v). Hence, by applying unit conversion factors and densities of CO_2 and CH_4, the annual biogas generation of food waste at UC was estimated to be 21.96 tons per year, with 8.83 tons being methane, this amount of methane can provide an energy output of 355,134 MJ, which is able to replace 12,767 m3 of natural gas for the natural gas-powered power plant at UC, if we compare this data is far from the real number in Universidad ICESI because our food waste significantly lower. However, the percentages of Biogas s per year and their tons of methane could give us and idea of how much biogas can we produce with the actual waste in the Institution.

Mexico

With the objective of reducing the pollution generated by organic waste and at the same time creating an alternative energy source, students from La Universidad de Guanajuato (UGTO) developed a plant to generate biogas from organic waste. The idea arose from an application by the Association of Traders and Products of Fruits, Pulses and Meats of Irapuato AC, in order to find a solution to the problem of the accumulation of organic waste produced by the central supply of the city of Irapuato. The idea was to transform this waste into biogas, for its subsequent use in electric energy. This materialized through a pilot project of a biodigestor of 10 thousand liters during 2013, and in 2015 already took place on an industrial scale (Gutiérrez, 2015). The project called Gas Verde: paquetetecnológicohacia la sustentabilidadeconómica, social, ambiental y tecnológicaen la gestión y aprovechamiento de basuraorgánica is projected to be applied in the 83 plants of supplies that are in all the country. However, so far it has only been applied at the Irapuato plant, which is the smallest and has a production of 20 tons of waste, of which only 10 tons are organic matter and the rest are recyclable materials. Laboratory-scale tests carried out in 10-liter reactors and validated on a pilot scale in a 10,000-liter biodigestor at a UGTO plant with the inoculum - bacteria isolated from the stomach of the cows - characterized and specialized for fruit residues and vegetables, converts one ton of waste into 50 thousand liters of biogas (Gutiérrez, 2015). As we can see here the project can be used for small quantity of food waste as well, this information could be practical in the university because they do not produce as much food waste as in Mexico does. However, we need to be careful with the time, the mixture is poured into the biodigester, where the consortium of bacteria feed on the sugar present in the fruit to convert it into biogas. It should be remembered that the organic matter has a decomposition period of about 30 days inside the digester (Gutiérrez, 2015). It requires almost a month for biogas to be available for the intended use.

Methanogenesis

Methanogenesis as the result of an anaerobic digestion is the oxidation of organic solids present in the biomass as represented with the equation below.

$$\text{Organic matter} + \text{Combined oxygen} \xrightarrow{\text{Anaerobic microbes}} \text{New cells} + \text{Energy for cells} + CH_4 + CO_2 + \text{Other end products}$$

Equation 1: *Anaerobic Action*

Source(Reynolds & Richards, 1977)

In General , organic matter, which in this case the food waste from the cafeterias and the mowed grass, is converted first into organic acids by acidogenic heterotrophic microorganisms and subsequently converted to methane and carbon dioxide by methane-producing heterotrophs, as seen in this figure:

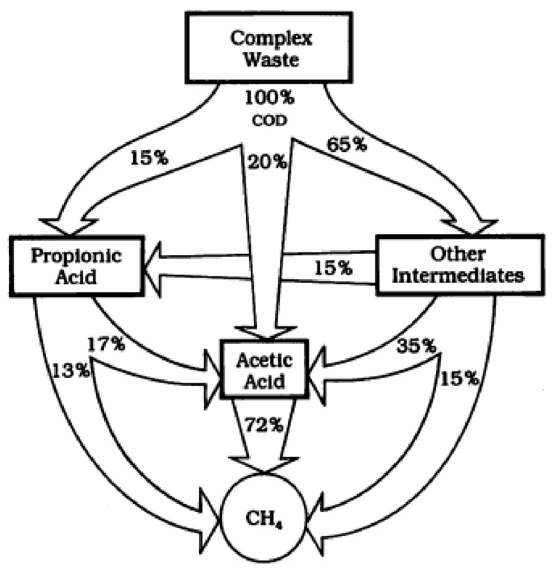

Figure 1: *Pathways for methane production from complex wastes*

Source (Reynolds & Richards, 1977)

The gaseous product of anaerobic digestion, Biogas (CH_4+CO_2), in general is composed by 50 to 75% methane CH_4 and 25 to 50% CO_2. Methane is a naturally-produced gas that comes from conversion of organic matter can provide renewable energy to be used for heating, and cooking, or even electricity generation or fuel if it is transformed to biomethane (Surendra, Takara, Hashimoto, &Khanal, 2014). Importantly, degradation of solids present in the manure results in a volume reduction of up to 50%, which is important because it contributes to sanitation and health problems caused by the mass disposal of organic residues (Reynolds & Richards, 1977). Additionally, while producing biogas reducing solids, treating biomass with anaerobic digestion also results in pathogen elimination and odor reduction, which improves general sanitation and quality of life (Weiland, 2010)

Biogas and Biomass

Biogas is primarily composed of methane gas, carbon dioxide, and trace amounts of nitrogen, hydrogen, and carbon monoxide. Biogas differs from natural gas in that it is a renewable energy source produced biologically through anaerobic digestion rather than a fossil fuel produced by geological processes (Christopher A, 2014). Agriculture and food residues are used in anaerobic bioreactors in many parts of the world to produce methane gas, which is used for the purpose of cooking and lighting. Since such waste materials are readily available in farms, rural people of many developing countries have been benefited from this technology. Besides, this technology is cheaper and simpler, thus, gaining popularity throughout the world (Gautama, Baralb, Herat, 2007).

According to Dinero (2016), the Latin-American energy demand by 2040 will be approximately 80% higher than current levels. This growing pressure stimulates emerging countries such as Colombia to adopt exploitation of new energy sources the reason of a new search of new energy sources and renewable energy is the high use of fossil fuels around 75% of the energy is provide by these fuels (World Bank, 2015).

Biomass is considered a renewable resource because is obtained from naturally-occurring processes (Fallis, 2013). Biomass has the potential to be converted into an enormous amount of energy. Raw materials like leaves, roots, nut shells, agricultural waste, waste wood, etc., are burned to produce steam. Biomass accounted for two-thirds of all renewable energy consumption in the European Union in 2012. In the United States, biomass energy consumption grew more than 60 percent between

2002 and 2013(Vannesa, 2016) Although in Latin America and the Caribbean, sustainable energy generation from biomass represented only 4 percent in 2014, biomass makes up the majority of the growth of installed renewable capacity in the region(Flavin C., 2014).

Anaerobic digestion (AD)

Is a process which breaks down organic matter in simpler chemicals components without oxygen. This process can be very useful to treat arising organic waste such as sewage sludge, organic farm wastes, municipal solid wastes, green/botanical wastes, organic industrial and commercial wastes

Before being digested, the feedstock has to undergo pre-treatment. There are various types of pre-treatment depending on the feedstock. The purpose of such treatment is to mix different feedstock, to add water or to remove undesirable materials such as large items and inert materials (e.g. plastic, glass) to allow a better digestate quality, a more efficient digestion and it will avoid failure in the process (Monnet, 2003).

The digestion process itself takes place in a digester, which can be classified in relation to the temperature, the water content of the feedstock and the number of stage (single or multi-stage). Each digester has its characteristics and properties and thus can be more suitable for a specific feedstock. There are at the present more mesophilic (35oC) than thermophilic digesters (55oC) but the difference tends to decrease (Monnet, 2003). Typically, the digestion process occurs optimally at pH of 7 to 7.2 with inhibition occurring outside of the range of 6.7 to 7.4 (Reynolds & Richards, 1977).

The by-products of anaerobic digestion, biogas and digestate, can be used in order to create a source of incomes. Biogas can be upgraded, most of the time by removing the carbon dioxide and the water vapour, and then, used in a CHP unit to produce electricity and heat. The digestate can be used as a fertilizer or further processed into compost to increase its quality (Monnet, 2003).

Anaerobic digestion has been widely applied for treatment of organic wastes that are easily biodegradable (Ten Braummeler, 1993). Many factors affect the design and performance of anaerobic digestion processes. Some of them are related to feedstock characteristics, reactor design and operation conditions (Hawkes, 1980; Fischer et al., 1986). The physical and chemical characteristics of the organic waste are important information for designing and operating anaerobic digesters, because they affect biogas production and process stability during anaerobic digestion.

Types of Anaerobic Digestion (AD) Technologies

Every type of biodigester's functionality is based on same basic principles, whether the feedstock is food waste, animal manures, or wastewater sludge (US EPA, n.d.). However, the design of biodigesters will vary according to the different needs and conditions where the AD Technology is being placed. Most common conditions for the variation of AD Technologies' design are described below, followed by description of digester categories.

Temperature

Digesters are principally feasible under every climatic condition. However, on low temperatures (mean temperature below 15°C), the results of biodigestion processes are not satisfactory (Vögeli, Riu, Gallardo, Diener, &Zurbrügg, 2014). Digesters are designed to run in to two typically range of temperature, which are: 30°C- 38°C and 50°C- 60°C (US EPA, n.d.). Those two ranges are called Mesophilic and Thermophilic respectively, and each one of them provides the temperature conditions for different populations of anaerobic microbes to survive. Typically, thermophilic digestion is used when greater pathogen kill is necessary (US EPA, n.d.), i.e. when the final solid product (fertilizer) needs to reach some certain quality standards (quantity of pathogens) in order to be sold (US EPA, n.d.). Moreover, Thermophilic digestion's rate of degradation is 50% higher, particularly with the fat-containing material (Vögeli et al., 2014). Also, in higher temperatures, due the lower solubility of CO_2, a 2%- 4% higher concentration of this gas is found. On the other hand, Mesophilic digestion process is more economic and stable, due the low monitoring process of temperature, and extra energy input associated with it, as the microbial communities can tolerate greater changes in environmental parameters and consume less energy (Vögeli et al., 2014). Yet, in the mesophilic range, microorganisms are slower and thus a longer retention time in the digester is needed to maximize biogas yield.

Feedstock variation

Digesters are designed to process either one type of feedstock or several types of feedstock. Co-digestion, is the name of a process that digestate more than one type of feedstock (Vögeli et al., 2014).

Inoculation and start-up

In the moment to start the digester for the first time, it is necessary to be inoculated (Introduce, cells or organisms, into a culture medium (inoculate | Definition of inoculate in English by Oxford Dictionaries, s.f.)), with bacteria necessary for the anaerobic process ideally diluted cow dung (optimally 1:1 ratio with water) (Kumara Behera& Varma, 2016). Typically, the minimum cow manure required for good inoculation amounts to 10% of the total active reactor volume, in other words, the more cow excrement used for inoculation process, the better. All along the start-up phase, the bacteria population needs to get gradually used to the feedstock, and to accomplish it, it is needed to progressively increase the daily feeding load which allows time to achieve a balanced microorganism population. Abrupt overloading during the initial phase, may put in risk the overall anaerobic process (Kumara Behera& Varma, 2016). Overloading is a consequence from either feeding too much biodegradable organic matter compared to the active population capable of digesting it, or rapidly changing digesters conditions (e.g. abrupt change of temperature, accumulation of toxic substances, flow rate increase). Those disturbances affect methanogenic bacteria expressly, whereas the acidogenic bacteria, which are more tolerant, continue to work, and produce acids. This situation entails, the eventual acidification of the reactor which inhibits the activity of methanogens (Vögeli, Riu, Gallardo, Diener, &Zurbrügg, 2014). The noticeable imbalance of bacteria types inside of the digester (acidogenic-methanogenic) may result in a process failure. Addition of manure can avoid this as it increases the buffer capacity, thereby reducing the risk of acidification (Kumara Behera& Varma, 2016). The gas that is produced in the first weeks after start-up is mainly carbon dioxide (CO_2). This gas is not flammable and can be released (Vögeli, Riu, Gallardo, Diener, &Zurbrügg, 2014). After a few days the methane content of the gas will have sufficiently increased to a level that can sustain a flame (CH_4>45 Vol.-%) and lead to high quality biogas (55 – 70 Vol.-%). (Vögeli et al., 2014)

Organic Load Rate

The Organic Loading Rate (OLR) is a measure of the biological conversion capacity of the AD system. It represents the substrate quantity introduced into the reactor volume in each time (Vögeli et al., 2014)

Hydraulic Retention Time (HRT)

The Hydraulic Retention Time (HRT) quantifies the time the liquid fraction remains in the reactor. It is calculated by the ratio of the reactor (active slurry) volume to the input flow rate of feedstock (Vögeli et al., 2014). The range of HRT of Mesophilic digestion process is from 10 to 40 days, while for Thermophilic digestion process the range of HRT reduces to very few days.

Operational Parameter	Formula	Description	Unit
Hydraulic Retention Time (HRT)	HRT = V/Q	HRT: Hydraulic retention time V: Reactor volume Q: Flow rate	days m^3 m^3/day
Organic Loading Rate (OLR)	OLR = Q*S/V	OLR: Organic loading rate Q: Substrate flow rate S: Substrate concentration in the inflow V: Reactor volume	kg substrate (VS)/m^3 reactor and day m^3/day kg VS/m^3 m^3
Gas Production Rate (GPR)	GPR = Q_{biogas}/V	GPR: Gas production rate Q_{biogas}: Biogas flow rate V: Reactor volume	m^3 biogas/m^3 reactor and day m^3/day m^3
Specific Gas Production (SGP)	Q_{biogas}/Q*S or GRP/OLR	SPG: Specific gas production Q_{biogas}: Biogas flow rate Q: Inlet flow rate S: Substrate concentration in the inflow	m^3 biogas/kg VS fed material m^3/day m^3/day kg VS/m^3

Table 1: *Main parameters for evaluation and comparison of different AD system performances*

Soruce (Vögeli et al., 2014)

Mixing

The benefits from mixing inside the biodigester, is to blend the fresh material introduced, with the already digestated manner, so the bacteria population living in the biodigester can inoculate the fresh material. This process also avoids aggressive changes of temperature and prevents scum formation. Scum, can block the gas pipe, so it should be avoided at its maximum. (Vögeli et al., 2014)

Classification of AD Technologies

The increasing rate of new technology development in the biomass treatment to obtain biogas or electricity, leaves the decision makers faced against numerous options from which to choose. From DIY (Do it yourself) types of biodigesters to fully automated industrial facilities. In this chapter, the reader will find the most common classification of Biodigesters, as described in most of the literature.

Total Solid Contents (wet/dry systems)

According of the percentage of solids in the substrate fed in an AD system, digesters are classified as dry or wet systems. Wet reactors, content 16% or less of total solids, while dry and semi dry reactors content 22% to 40%. Dry digesters are considered better over the wet digesters, because the size of the reactor is smaller, there is a smaller demand of energy for its functionality, and minimal material handling effort. (Vögeli et al., 2014)

Feeding Mode

Biodigesters can be fed continuously, i.e. the reactors are filled with feedstock at regular times, while an equivalent amount of digestate leaves the digester. This kind of process does not need mixing, because being constantly fed, is the equivalent of being mixed. (Vögeli et al., 2014). On the other hand, there are the batch-fed, digesters, that are fed once, and then closed, until the HRT is over, then open again and emptied.

Operating Temperature

As discussed before, there are two types of biodigesters classifications by temperature: Mesophilic and Thermophilic, that operates at the ranges of 30°c-40°C and 45°C-60°C respectively.

Number of Stages

Concerning to biodigesters, several stages means more than one reactor. Optimizing this reactions separately in different stages or reactors, may lead to a larger overall reaction rate and biogas yield (Vandevivere, De Baere, &Verstraete, 2016). According to Vandevivere, two stages are used where the first one harbors the liquefaction-acidification reactions, with a rate limited by the hydrolysis of cellulose, and the second one harbors the acidogenesis and methanogenesis, with a rate limited by the slow microbial growth rate. Thus, it becomes possible to increase the rate of methanogenesis by design the second reactor with a biomass retention scheme. However, Vandevivere discuss that this kind of system does not necessarily provide a higher rate of gas production, but a greater biological reliability for waste that causes unstable performance in one stage system.

Examples of Anaerobic Digestion Technologies

Nowadays exists numerous models of biodigesters, that fit to the decision-making agents' different combinations of needs. The choice of the design is influenced by technical suitability, cost-effective-ness, and the availability of local skills and materials (Vögeli et al., 2014). Here are examples described below.

Fixed dome digester

This kind of biodigester is generally built underground, and it was built for the first time in china in 1936 (Ramatsa, Akinlabi, Madyira, &Huberts, 2014). The dome is fixed, and hence the name of the digester. The gas produced in the digester is stored in the upper part of the reactor. With a closed outlet gas valve, increasing gas production elevates the gas pressure inside the digester thereby pushing the digestate into the compensation tank (Vögeli et al., 2014). When the gas valve is open for gas utilization, gas pressure lowers its levels and then a proportional amount of slurry enters from the compensation tank in to the digester. Because of this, the pressure of the gas varies trout the time.

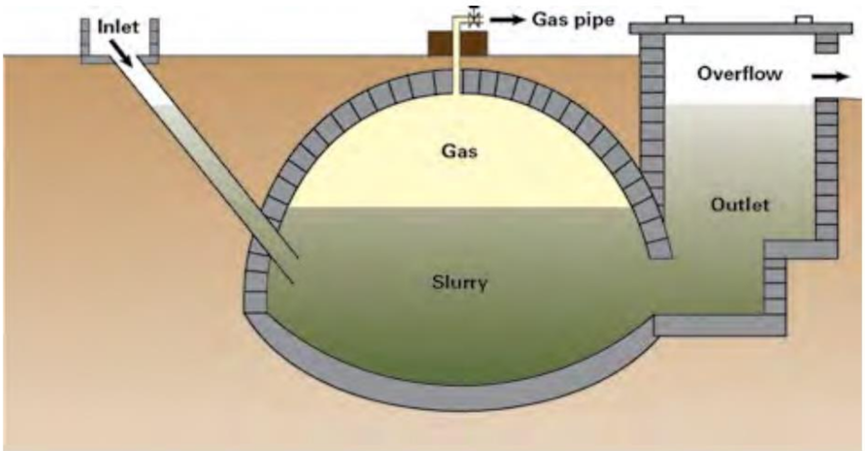

Figure 2: *Scheme of a fixed-dome digester*

Source (Vögeli et al., 2014)

Advantages	Disadvantages
• Relative low construction costs • Long life span if well-constructed • Absence of moving parts or corroding metal parts • Underground construction saves space and protects the digester from temperature fluctuations • Local construction provides opportunities for skilled local employment	• Certain specific technical skills are required to ensure a gas-tight construction • Fluctuating gas pressure depending on volume of stored gas • Special sealant is required for the inside plastering of the gasholder (e.g. bee wax–engine oil mixture, acrylic emulsion) • Gas leaks may occur when not constructed by experienced masons • Difficult to construct in bedrock • Difficult to repair once constructed as the reactor is located under soil

Table 2: *Advantages and disadvantages of a fixed-drum digester*

Source (Vögeli et al., 2014)

Floating-drum digester

This Indian model started in 1937. This popular design is known as Gobar Gas plant. (Ramatsa et al., 2014), consist of a cylindrical digester and movable-floating gasholder. The collected gas, depending of its amount makes the drum rise or fall. This rise or fall is a good visual indicator for monitoring the amount of gas in the digester. The gas has a constant pressure, depending on the weight of the drum. However, this weight can be modified by adding additional weights in the top of the drum, in order to change the pressure of the gas.

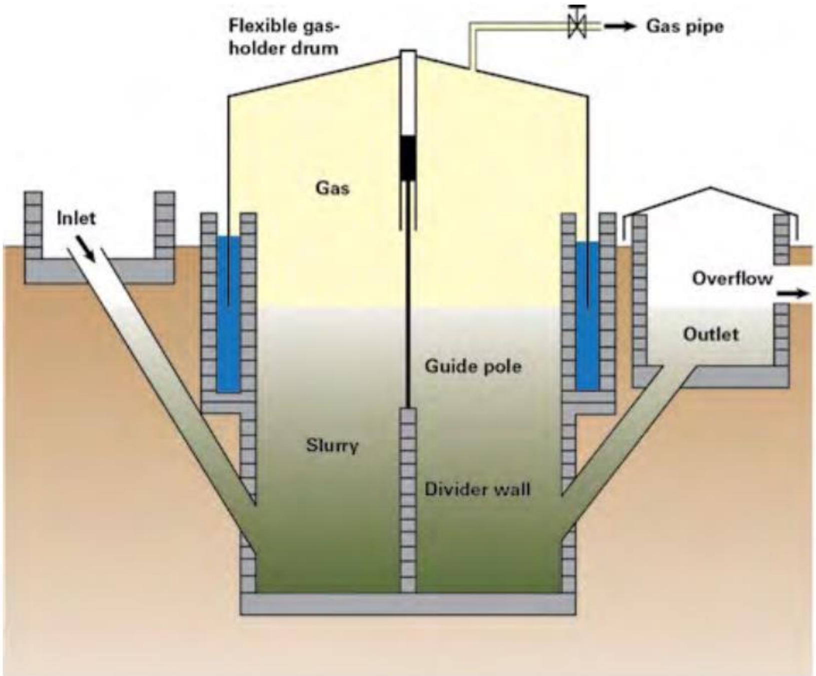

***Figure 3**:Scheme of a floating-drum digester*

Source (Vögeli et al., 2014)

Advantages	Disadvantages
• Simple and easy operation • The volume of stored gas is directly visible • Constant gas pressure • Relatively easy construction • Construction errors do not lead to major problems in operation and gas yield	• High material costs for steel drum • Susceptibility of steel parts to corrosion (because of this, floating-drum plants have a shorter life span than fixed-dome plants) • Regular maintenance costs for the painting of the drum (if made of steel) • If fibrous substrates are used, the gasholder shows a tendency to get "stuck" in the scum layer (if gasholder floats on slurry)

***Table 3**:Advantages and disadvantages of floating-drum digester*

Source (Vögeli et al., 2014)

Tubular Digester:

A tubular biogas plant consists of a longitudinal shaped heat-sealed, weather resistant plastic or rubber bag (balloon) that serves as digester and gas holder in one (Vögeli et al., 2014). This digester is very low cost, yet has a lot of disadvantages, like the possibility to be damaged by putting more weight (heavy elements) on it, in order to increase the pressure of the gas. Moreover, due to its shape, the active mixing is limited and di- gestate flows through the reactor in a plug-flow manner.

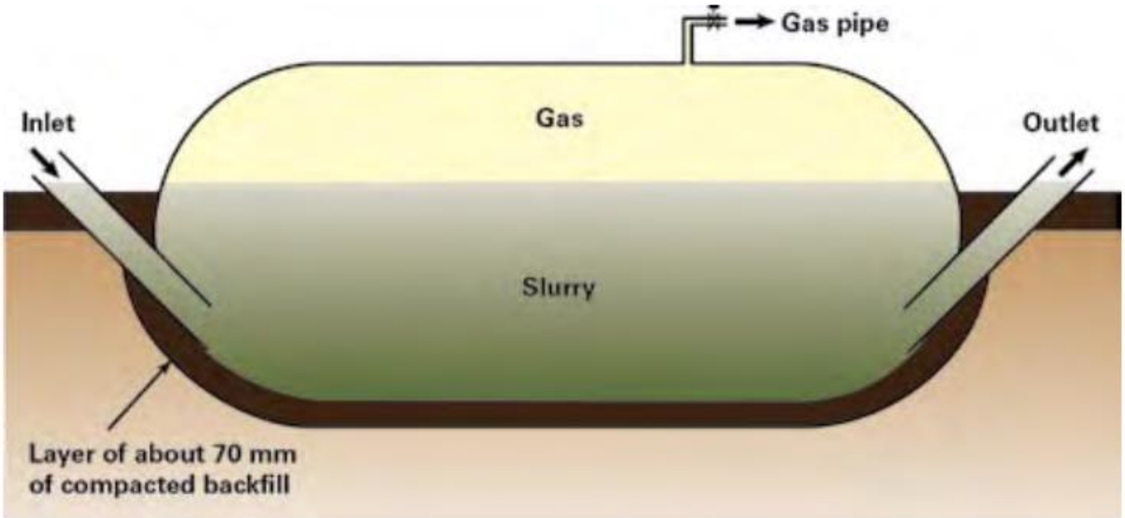

***Figure 4**: Scheme of a tubular digester*

Source (Vögeli et al., 2014)

Advantages	Disadvantages
• Low construction cost • Ease of transportation • Easy to construct • High digester temperatures in warm climates • Uncomplicated emptying and maintenance • Shallow installation depth suitable for use in areas with a high groundwater table or hard bedrock	• Relative short lifespan • Susceptibility to mechanical damage • Material usually not available locally • Low gas pressure requires extra weights • Scum cannot be removed from digester • Local craftsmen are rarely in a position to repair a damaged balloon

***Table 4:** Advantages and disadvantages of a tubular digester*

Source (Vögeli et al., 2014)

Garage type digester

On the contrary for the other 3 biodigesters already presented, this particular one is a dry-batch-mode biodigester. The entire organic waste stream is filled batch-wise into a simple garage-like digester with an airtight door. Once the door is closed, the material does not need to be transported or turned during the process (Vögeli et al., 2014). As already discuss before, this biodigester receives the name of dry, only because its concentration of total solids is at least 40%. However, the other 60% remaining is water, because it is essential for the population of bacteria to survive.
The fresh material is, yet, inoculated with old digestate, or with fresh cow dung. After the door is closed, an internal system of irrigation of percolated material, spread its content all over the slurry and disperses the AD bacteria evenly in the system. The irrigation process is regularly active on the time of gas production. Few days before the HRT is over, the percolated irrigation is stopped to allow dewatering of the digestated material. (Vögeli et al., 2014). After the HRT is finished, the digester is flushed out with the gas before opening.

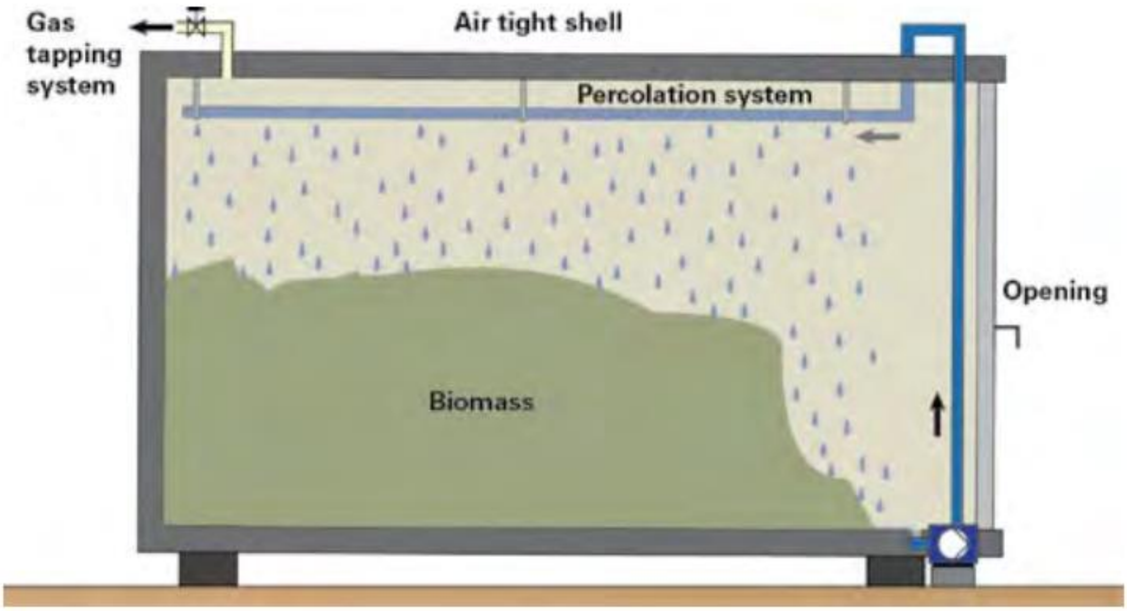

Figure 5: *Scheme of a garage type digester*

Source (Vögeli et al., 2014)

This type of biodigester needs a parallel system of several batch-fed digesters in order to ensure continuous gas production, because of the inoculation process.

Advantages	Disadvantages
• Simple design • Only little water addition is needed • Easy treatment of digestate	• Gas-tightness of opening difficult • Inoculation is needed for every new batch, thus reducing capacity for fresh feedstock

Table 5: *Advantages and Disadvantages of a Garage type digester*

Source (Vögeli et al., 2014)

METHODOLOGY

Objective 1: Identify and estimate organic waste streams at ICESI using university data bases and direct quantification

The first step of the project entails quantification of the available organic waste streams at the university, including table food waste, kitchen food waste (i.e. vegetable and fruit peels, eggshells, etc.) and yard waste.

Critical activity 1.1 (CA 1.1): Consultation with SOMA database information

To begin quantifying organic and inorganic wastes generated over the span of a year at the university, SOMA (SaludOccupacional y Medio Ambiental) was consulted to determine what existing information on waste generation was available. To this end, historical records of residues for each cafeteria over 2016 were obtained. This data is important because it provides a clear picture regarding variations in monthly waste generation, illustrating high and low seasons that reflect fluctuations in students present at the university. However, it should be clarified that these residues do not account for table waste (i.e. Aguamasa). Rather, this data only represents “ordinary” waste (i,e, ordinary garbage). However, as mentioned above, this information provides a useful reference for waste generation variation, which will permit estimation of annual food waste, in combination with direct data on aguamasa generation at the university. That is, if an average value for aguamasa can be determined, as outlined below, the proportion of aguamasa to ordinary waste can be determined, and then extrapolated to calculate annual flux in aguamasa as a function of existing ordinary waste production.

Moreover, SOMA provided another data base of historical records of the total amount of daily kitchen waste generated from the university. Due the fact that the collection of this kitchen waste is separately from any other type of waste, for its final disposition, as well with the measuring process, it will be directly account as organic waste for the main propose of this project.

Critical Activity 1.2 (CA 1.2): Food waste estimation

It is an important consideration that table food waste form cafeteria lunches was not accounted for in the information collected and provided by SOMA, and this waste is currently being disposed of outside of the university, with 30 and 40 gallon barrels, with a similar geometry of a cylinder, of organic waste removed from the university every Wednesday and Friday. Thus, to quantify the production of weekly aguamasa, the barrels will be assumed to have a standard geometry of a cylinder, in which the diameter and height of each one of them are going to be premeasured. Once the dimensions of the barrels are known, the cleaning staff from the university will full them up with the table food waste that is being left by the costumers of the two main cafeterias in the campus. The height until the barrels are full with food waste, is going to be recorded in an Excel spreadsheet before leaving the university on a weekly basis during the regular school schedule. Afterwards, the data from the measured height, is going to be plugged with the diameter of each premeasured barrel, in order to obtain the volume stored in. The sum of the storage of each barrel per week will give an estimated volume of food waste being produced in the university. By combining the volume of waste generated and the density of this type of waste, a value for an average of weekly Kg of aguamasa can be obtained (Gallardo, 2016).

Aguamasadensity was calculated using by measuring the mass of 250mL of food waste in a 500 ml beaker, the volume of which was calibrated water first. Specifically, assuming a water density of 1, the beaker was marked with a line, using a permanent marker, on the level where water reached 250 grams, in order to obtain a fixed volume of 250 ml. Then, the beaker was filled with Aguamasa until the marker line. As the consistency of Aguamasa is high in moisture content, it can exhibit liquid -ike properties, facilitating simple volume measurements. Density was obtained by dividing the mass weighted from the beaker filled with Aguamasa by 250 ml which was done for a total amount of 6 times from two different sampling intervals.

Critical Activity 1.3 (CA 1.3): Yard waste estimation

Significant amounts of yard waste are collected at university, and part of it is treated in an on-campus compost operation. Consultation will be taken to quantify weekly production of this organic waste as well, which could possibly be used as a substitute substrate for use during low periods in aguamasa production. However, due to its lignocellulosic nature, it is expected that digestion times will be longer than that of Aguamasa, and feeding consideration must be made for this different substrate. Yet, due to the great diversity of plants inside the campus, and the significant amount of yard waste collected in the university, quantification of yard waste in mass terms requires further study, and will not be undertaken here.

Objective 2: Estimate the potential annual biogas production for identified waste streams at the university using data from previous work, considering seasonal variation.

Critical Activity 2.1 (CA 2.1): Biomethane potential (BMP)

Biomethane potential (BMP) analysis was done for Aguamasa, from Biodigesters (Medina, 2017) at 1 L laboratory scale. These results were generated from a separate ongoing thesis from ICESI university in FCN (Facultad de CienciasNaturales), which was completed in December 2017. This study took a sample of aguamasa produced in the university each day of one scholar week in September of 2017 (Medina, 2017). In order to quantify the total of volatile solids (VS) of this kind of food waste, a fraction between 18% and 25% of each sample was dried at 110°C for 24 hours, and then dried for extra 24 hours at 500°C. The difference in mass of the samples before and after the process, gave as a result the VS. The Ph data was taken through a Phmeter.

Monitoring of biogas production was performed continuously with flow meter at 35 ° C. A 1: 6 ratio of percentage of volatile solids (%VS) substrate per %VS of inoculum was used, where the base inoculum came from a municipal anaerobic digester located in Cali (Medina, 2017). The volatile solids concentration (VS) of the inoculum was 0.61% by weight. The volume of the sludge used was sufficient to occupy 65% of the total volume of each reactor. The gas volume was determined by means of flow meters which report the gas accumulated during the experiment, and reported in mL biogas per g VS. Biogas composition was analyzed with a Biogas5000 portable biogas analyzer (GEOTECH, UK).

The results obtain by the process described before, were used to estimate the total potential amount of biomethane that the waste quantified in CA1 would produce when digested. Using the weekly average mass of aguamasa produced by the university and multiplying it by the average total volatile solids percentage would give as a result a weekly mass of volatile solids from aguamasa. Repeating this same process, but using the average BPM value instead of the %VSS, a weekly volume of biomethane was estimated.

Critical Activity 2.2 (CA 2.2): Estimatefertlizer weekly and annual biogas production.

Weekly and annual potential biogas production was calculated, using quantified food waste data, in combination with BMP analysis as generated by previous project data(Medina, 2017).Fertilizer content will be estimated using nutrient content of effluents from a pilot digester on campus being fed Aguamasa (Peterson et al. 2017).

Objective 3: Evaluate economic benefits for implementing a tubular Biodigester technology

Critical Activity 3.1 (CA 3.1): Consider costs/benefits

Using the designs from the previous CA 3.1, this project will evaluate the economic feasibility of each one of them. For this economical evaluation, all the associated costs of the life cycle for these technologies will be taken into account. For this purpose, the project will follow the methodology in "*Introduction to renewable energy*" (Nelson &Stracher, 1982), calculating the Life Cycle Costs (LCC) as follows:

$$LCC = IC + M_{pw} + E_{pw} + R_{pw} - S_{pw}$$

Equation 2: *Life cycle cost*

Source (Nelson &Stracher, 1982)

Where IC, is the initial cost of installation, $M_{pw}$is the sum of all yearly operational and maintenance costs, $E_{pw}$is the energy cost (sum of all yearly fuel costs), $R_{pw}$is the sum of all yearly replacement costs, and S_{pw} is the salvage value (net worth at the end of the final year). The initial cost, can also be discounted for some benefits that the Colombian government, which there offerto all who want to install renewable energies systems, which will be discussed below.

According to Nelson and Stracher, future costs must be accounted for because of the time value of money, so it is necessary to calculate the present worth of each cost for each year. Life span of a Biodigesters system depends on the specifications of each design. Moreover, the lifespan of a renewable energy system is assumed to be 20-40 years. (Nelson &Stracher, 1982). If each cost and benefit over the lifetime of the system were brought back to the present and then summed, the present worth can be determined as follows

$$PW = \frac{(Cost\ totla\ for\ year\ S) - (Financial\ benefit\ total\ for\ year\ S)}{(1+d)^M}$$

Equation 3: *Present Worth calculation*

Source (Nelson &Stracher, 1982)

Where cost total is the negative cash flow, S is the specific year in the system lifetime, M is the years from the present to year S, and d is the discount rate.

Critical Activity 3.2 (CA 3.2): Consider space and environmental impact

The environmental impact will be evaluated, using the already created tool by IcesiUniversity which measures the institutional ecological footprint. In this tool it is allowed to calculate what is the total CO_2 tons equivalent for each ton of any waste, for our case 3 types of factors were used(Rodríguez & Enriquez, 2018). The first case is for the ordinary waste calculated in the critical activity CA 1.1. However, the incineration factor and the sanitary landfill were be used for the values of CA 1.2, which are the university's way of life of these wastes. As it is expected, the implementation of a system of anaerobic digestion should diminish the value of the actual footprint, positioning the University Icesi as one of the pioneers in implementing this kind of ecological technology, among other educational institutes in Colombia. Moreover, the score of waste management from the university, evaluated by UI Green Metric (List of Universities in Each Country (2016) | UI GreenMetric, s.f.), could be improved as well.

RESULTS

Objective 1: Identify and quantify organic waste streams at ICESI using university data bases and direct quantification

Critical activity 1.1 (CA 1.1): Consultation with SOMA database information

To gain an overall perspective of general solid waste production at the university, initial analysis of databases provided by Soma. It can be seen in Figure 6 that production reaches values between 6 to 7 metric tons monthly. However, it is also apparent that seasonal variation occurs with respect to waste production, with decreases in production in June and December representing less than 50% of regular production. This is understandable since student attendance is lower during these months, in comparison to February to May and August to November, during the typical school calendar year. Thus, while the year average production is 4.81±, 1.21 tons/ month, the average value excluding December and June is 5.055 tons per month, which reflects general waste production during typical use operation, while average values for January-December and June represent 2.40 ±, 0.04 tons/month, representing typical waste production during the holiday periods.

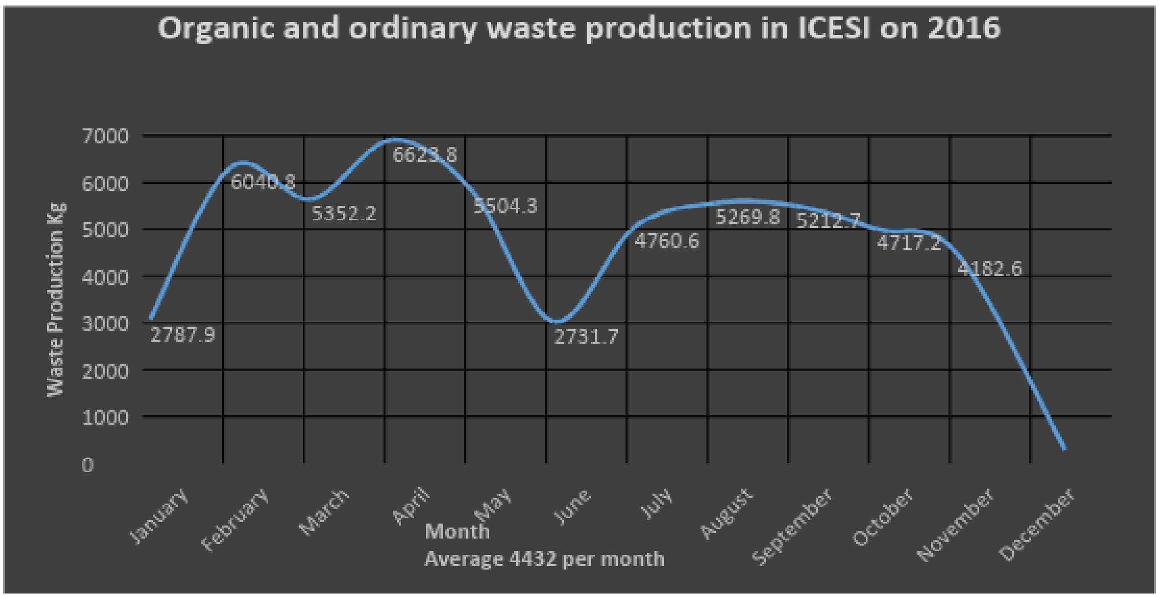

Figure 6: *Organic and ordinary solid waste production for Icesi University in 2016*

However, it should be noted that the data provided here represents a combination of inorganic and organic waste (i.e. garbage cans) anddoes not directly reflect substrate availability for anaerobic digestion due to high inorganic loadings. However, this data does provide useful information on the fluctuations of waste production due to variations in the calendar year, helping to estimate the demands that would be placed on an anaerobic digestion system. Thus, an anaerobic digester could expect a reduction in 50.21% during the vacation periods.

Similarly, SOMA shared database information on organic waste production from the cafeterias, providing information on the quantities of uncooked organic waste produced in the kitchens (i.e. vegetable peels and egg shells). It can be seen in Figure 7 that over 145.22 kg±17.44 kg is produced per week, representing weekly and month production rates of 675.25±135.38 kg and 2921.25± 205.84 Kg respectively. While this material is indeed suitable for anaerobic digestion, and is important with regards to organic waste handling at the university, currently this waste stream is dedicated to the compost process, and not under consideration for anaerobic digestion at this time. The reason for this is because the water mass represents a higher BPM so it could affect the total yield of the biodigester.

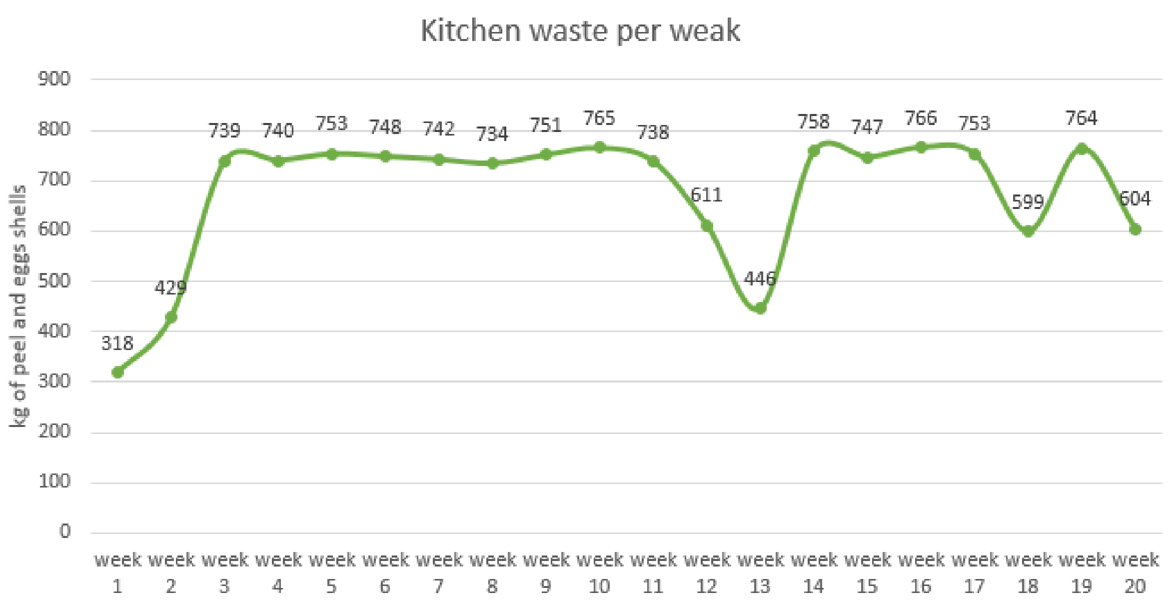

Figure 7: *Average daily kg of kitchen waste*

Critical Activity 1.2 (CA 1.2): Food waste estimation

Overall, the core contribution of this work is then the quantification of aguamasa, which has no current use in university operations and represents an excellent candidate for food waste- biogas production. Aguamasa here represents the food residues or leftovers scraped from plates at two principal cafeterias in the campus. This food waste has been quantified volumetrically, and converted in mass via basic density measurements.

As can be seen in Figure 8, over the span of a semester there was a large spike in the volume of this organic waste measured in the first week of data collection, followed by values leveling off near half a cubic meter per data collection point. The current estimates suggest the university cafeterias produce 0.142 ± 0.04 m^3per day, and 0.85 ± 0.16 m^3per week when examining more or less constant operation as represented by weeks 2-16, It is likely the large outlier in week one represents a peak in waste production as result of the re-initiation of kitchen operations after the holiday break, and thus does not reflect typical operation. However, in the 9th week, there was a decrease in the measurement due to that week there was a holiday on Monday and Saturday (i.e. Semana Santa, or Easter Week), so it is normal that the volume measured is below the average that had been measuring. Considering the high number of holidays in Colombia, these reductions in production should be considered commonplace and accounted for.

Additionally, densitymeasurements were taken to calculate organic waste produced by the cafeteriason the basis of mass as well. An observed densityvalue of 1.23g/ml estimates an average value of 1.11±0.44tons of organic waste each week. This waste represents only that which came from the scraped dishes of the cafeterias, providing distinctly different information compared to that provided by SOMA.

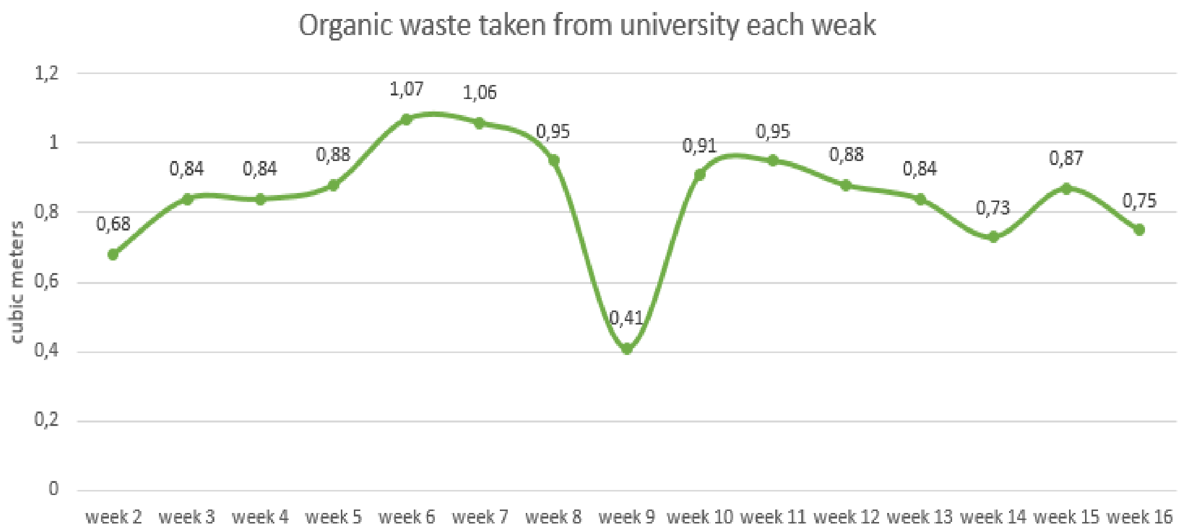

Figure 8: *Organic waste taken from university each week*

Critical Activity 1.3 (CA 1.3): Yard waste estimation

Month	Yard Waste (m^3)
January	94
February	114
March	100
April	72
May	126
June	54
July	88
August	72
September	36
October	18
November	30
December	91
Total	895

Table 6: *Monthly yard waste in cubic meters produced by the university*

Yard waste was quantified for weekly production of this organic waste as well, which could possibly be used as a substitute substrate for use during low periods in Aguamasa production. This database was provided by SOMA, shows the total yard waste produced by the university on 2017, it is observed a total of 895 cubic meters of organic wasteas can be seen in Table 6. While, these residues are not the most convenient for the current chosen Biodigesters technology for their lack of moisture components, the yard waste has a better use in the composting plant where its real utility is to become compost. However, some could be diverted to provide substrate during holiday periods.

Objective 2: Estimate the potential annual biogas production for identified waste streams at the university using data from previous work, considering seasonal variation.

Critical Activity 2.1 (CA 2.1): Biomethane potential (BMP)

As stated before, partial results from this activity were taken from another ongoing thesis from the FCN in the university(Medina, 2017). From this thesis, very important information for the technical and economic study were obtained, including volatile solids (VS), pH and BMP of the characteristic Aguamasa produced in the cafeterias of the campus.

Sample	%VS	% Humidity	pH
Monday	18.86	81.14	4.95
Tuesday	25.03	74.97	5.24
Wednesday	19.78	80.22	5.25
Thursday	18.21	81.79	5.21
Friday	19.21	80.79	5.14
Average	20.22	79.78	5.16
Standard Deviation	2.75	2.75	0.12

Table 7: *%VS %Humidity and pH values obtain for aguamasa samples*

Source (Medina, 2017)

As seen in the table 7, the %VS percentage of this type of waste, can be beneficial for the usage of both types of reactors, wet and in dry types. Given the case that the final consideration for this Project is a wet reactor, it is only needed to add some water in order to decrease this percentage. According to Medina, the pH values in order to have a good methanogenic process should be around 6.6 to 7.6. However, Aguamasa showed lower pH value (4.9-5.2), but this may be beneficial, as it indicates acidogenesis has begun naturally, which could reduce solid retention time. However, more studies should be done to characterize this possible effect, taking account for constant monitoring, and extra processes in order to increase this value.

In the next table, the BMP is provided in units of milliliters of biogas per grams of volatile solids. HGM samples, in Medina's study, states for homogenized samples i.e. manually mixed samples, in order for the components of the Aguamasa to be well homogenized. As it is shown in the table 8, and according to Medina, the values of BMP for Aguamasa are consistent for solid organic waste BMP reports (0,300 to 0,570 m^3/Kg VS). Thus, Aguamasa produced in the campus cafeterias is indeed a good subtract for the production of methane, and it is expected a great performance for its production in a bigger scale (Medina, 2017)

Sample	BMP (mL Biogas/g VS)
Monday	848.63
Monday HMG	510.75
Tuesday	768.75
Tuesday HMG	692.03
Wednesday	392.89
Wednesday HMG	489.91
Thursday	755.60
Thursday HMG	489.91
Friday	732.41

Friday HMG	574.03
Average	625,69
Standar deviation	144.93

***Table 8**: BMP reports mL biomethane / g VS*

Source (Medina, 2017)

Critical Activity 2.2 (CA 2.2): Estimate weekly and annual biogas production.

Plugging the average percentage of volatile solids found by Medina in her project, with the data collected in CA2, the total weekly volatile solids was calculated. As it can be seen in figure 9, and in table 8, the range of values where the weekly total volatile solids can be found is from 0.1 tons until 0.45 tons, with an average of 0.23 ± 0.09 per week.

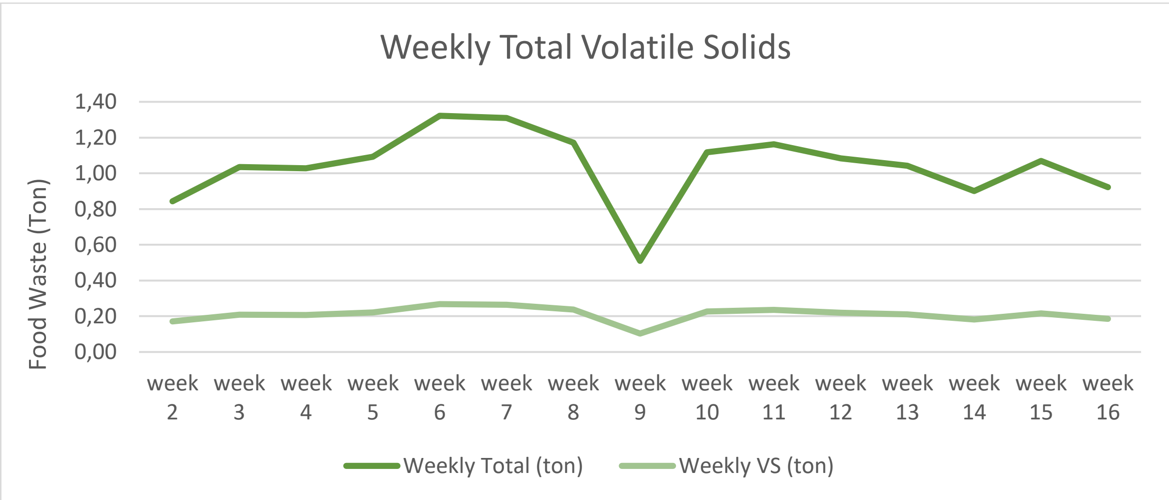

***Figure 9:** Weekly Total Volatile Solids*

Using this weekly biogas production was estimatedbyextrapolating the average BMP values found in Medinas work to the total volatile solids obtained in the study presented here (Figure 9). As can be seen in Figure 10, The range of values for weekly BMP werebe foundto 40.54 m3 until 105.81 m3 with an average of 140.89± 55.17 m³ per week.

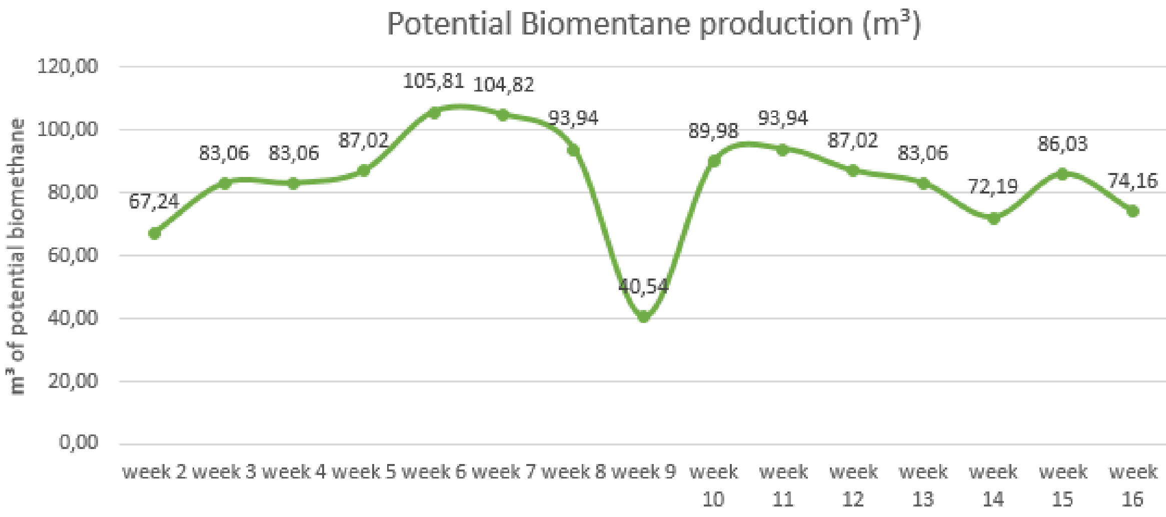

Figure 10: *Potential biogas production (m3)*

Semester week	Weekly Total (Ton)	Weekly VS (ton)	Weekly Potential biogas
1	2,21	0,45	279,56
2	0,84	0,17	106,64
3	1,04	0,21	131,00
4	1,03	0,21	130,06
5	1,09	0,22	138,10
6	1,32	0,27	167,18
7	1,31	0,26	165,64
8	1,17	0,24	148,18
9	0,51	0,10	64,63
10	1,12	0,23	141,39
11	1,16	0,24	147,00
12	1,08	0,22	137,16
13	1,04	0,21	131,79
14	0,90	0,18	114,06
15	1,07	0,22	135,24
16	0,92	0,19	116,63
Average	1,15	0,23	145,44
Standard deviation	0,44	0,09	55,67

Table 9: *Weekly Potential biogas per Weekly VS (ton)*

For the next table, the percentage of methane present in the biogas produced is reported. This data is consistent with the information provided in the reference framework of this project, for the amount of methane present in the biogas produced for any type of technology. It is expected to have a good performance of aguamasawhen being treated for the portion of biogas in a larger biodigester.

However it is important to clarify that every technology has an efficient rate, which in some cases could produce a lower amount of biogas, and/or a lower rate of methane.

Sample	CH4/g	%CH4
Monday	529.851	62.436
Monday HMG	390.969	76.548
Tuesday	471.275	61.304
Tuesday HMG	447.92	64.539
Wednesday	246.138	62.648
Wednesday HMG	298.296	60.888
Thursday HMG	409.425	55.901
Friday	364.888	63.566
Friday HMG	394.845	63.479
Average	394.845	63.478
Standard Deviation	55.12	7.63

Table 10: *Methane percentage reports*

Source (Medina, 2017)

Estimation of annual Biomethane production

It is assumed that Biomethane production will be constant for the whole year, thus to calculate the estimation the weekly average Aguamasa production (1,05 Ton/week) and then multiplied by 4, assuming that each month has 4 weeks giving as a result 4.2 Ton/month. After the estimation of the monthly production of Aguamasa, the average %VS (20, 22 %), the average BPM (625, 29 M3 biogas / Ton VS) and the average %CH4 (63, 47 %) is applied to it in order to obtain a monthly Biomethane production i.e. 337,039 m^3. Lastly to obtain the annual Biomethane production the average monthly Biomethane production is multiplied by 12 giving as a result 4044.47 m^3

Objective 3: Evaluate economic benefits for implementing a tubular Biodigester technology

Critical Activity 3.1: Consider costs/benefits

Installation and construction costs

To begin economic evaluation, the amount of square meters needed for the installation of the Biodigester was determined, and this process is divided into two parts. First, according to the provider (Biobolsa), the size of the Biodigester is: 15m long x 2,20m with x 1,20m deep, since the Biodigester would be installed in a previously excavated site on campus. Consequently, the area that the Biodigester used was: 33 square meters. The estimated cost for each square meter of soil excavated in the university is 2'000'000 COP (this information was provided by the Physical Department from the campus), with the price including a gas connection to the university network. However, an extra area should be considered in order to expand the Biodigester,since the pouring of the waste cannot be made in a very small area, thus an extra 2 meters are considered for this evaluation.There should be also another extra area to consider, in orderto place a storage and control room, where the unprocessed waste and other tools could be keep in place. A 10 square meters room with air and water connection, was considered in this study. The water connection is really important to be taken in account since the Biodigester will use a 1:2 ratio of aguamasa and water in order to produce biogas.

	With	Long	Area	
Biodigester Area	2,2	15	35	approach
Storage room + expansion Area+ Biodigester Area	2,2	20	45	expansion

Table 1111: *Biodigester measurements*

Cost	Area (square meter)	Cost per square meter	Installation cost
Biodigester Area	35	$ 2.000.000,00	$ 70.000.000,00
Storage room	10	$ 2.500.000,00	$ 25.000.000,00
		Total	$ 95.000.000,00

Table 122: *Cost of construction and installation of the Biodigester.*

The costs per square meter are not only the costs of the land, these are precise cost per square meter built, this includes the installation to the gas network, drinking water and sanitary part if necessary, the university does not have the cost of a square meter that is not built so this value includes construction and installation.

Biodigester Cost

The following values were obtained from a quote made with the BIOBOLSA Company, which includes the cost of the Biodigester, transportation cost from Bogota to ICESI, supervision of the installation and training for the people who will be feeding the Biodigester.

Item	Cost
Biodigester BB40	$ 9.163.000,00
Transportation cost	$550.000,00
Training and technical assistance	$ 1.000.000,00
Total	$ 10.713.000,00

Table 133: *Cost of the biodigester and transportation.*

Water Usage Cost

As stated before, this Biodigester is going to use a 1:2 water and Aguamasa ratio (2 kg of water per Aguamasa kg). The m3 of water cost provided by Emcali for the industrial is 6,239 COP. Thus, water usage cost (WUC), assuming density of water 1 g/ml is:

$$WUC = Estimated\ annual\ aguamasa\ production\ (ton) x\ 2 \frac{m^3}{ton} x \frac{price}{m^3}$$

$$WUC = 53.04\ ton\ x\ 2\ \frac{m^3}{ton} x\ \frac{6{,}239\ COP}{m^3} = 661{,}833.12\ COP$$

Equation4:*waterusagecost*

Faltan costos de mantenimiento, de distribución y nuevas estufas para su uso! La bomba de flujo para evitar variaciones y sobre todo los cartuchos para remover H_2S, como mínimo.

Biodigester Feeding Cost

In this study is assumed the hiring of a one new person for the control and management of the installed Biodigester. This person will be payed a Colombian minimum wage as stated as follows:

Colombian Minimum Wage	
Minimum wage	$ 781,242.00
Transport	$ 88,211.00
Layoffs	$ 72,454.42
Interest	$ 8,694.53
Vacations	$ 32,551.00
Bonus	$ 72,454.42
Total	$ 1,055,607.37
Annual	$ 12,667,288.44

Table 144: *Colombian Minimum wage components*

Avoided Natural Gas Cost

In order to calculate the savings (Avoided Natural Gas Cost ANGC) on gas consumption provided by the Biodigester, it is necessary to multiply the market cost of m3 of natural gas for the commercial sector (4,082 COP) times the annual estimation of Biomethane production, thus:

$$ANGC = Estimated\ annual\ Biomethane\ production\ m^3 x \frac{Price\ Natural\ gas}{m^3}$$

$$ANGC = 4{,}044.47\ x\ \frac{4{,}082}{m^3} = \$16{,}509{,}526.54\ \text{COP}$$

***Equation 5**: Avoided Natural Gas Cost*

As table 15 states, the biggest consume of natural gas is made by the Isabella Piso1 cafeteria, in which the Biodigester would contribute with approximately to 45, 36% of its annual needs.

Cafetería	Total Consumption 2017-1 (M3)	Total Consumption 2017-2 (M3)
619840 Isabella Piso 1- Contador 1	4396	4505
619843 IsabelaPiso 1 - Contador 2	3220	2591
619844 The Snack	893	894
1591672- Local 2- The Snack	900	913
619859 Menta y Sabor	730	661
1591678 - Antony Chef	813	665
1622335 -Bristo- Cafeteria 2	2692	2450
629792 La Plazoleta	443	494
619861 BienestarUniversitario	12	14
629793 Edif L- Piso 1	89	19
683364 CocinetaServicios	187	220
2014649 PiscinaPatinodromo	0	2169
337447-Casa San Joaquin	0	0
TOTAL	**14,375**	**15,595**

***Table 155:** Total Natural gas consumption Icesi 2017*

Avoided Incineration Costs

Currently the university is incinerating the aguamasa produced inside the campus, because food waste cannot be directly disposed in a normal Landfill, since it is considered to be dangerous. This incineration process has a cost of 600 COP per aguamasa KG. In order to calculate the incineration savings (Avoided Incineration Costs AIC) it is needed to multiply the cost of incineration times the annual aguamasa production, thus:

$$AIC = Estimated\ annual\ aguamasa\ production\ ton\ x\ \frac{1000\ kg}{ton} x \frac{incineration\ price}{kg}$$

$$AIC = 53{,}04\ ton\ x\ \frac{1000\ kg}{ton} x \frac{600\ cop}{kg} = 31{,}824{,}000\ COP$$

Equation 6: *Avoided Incineration Costs*

Table 16 shows a compilation of financial costs and financial benefits for the first year of the project. At the end of the table there is one benefit that is not taken in account in the economic evaluation of the project i.e. the selling of the remaining organic fertilizer that is produced daily. According to the provider, the production of fertilizer goes up to 550L per day. One Hectare of green area can be fertilizing with up to 1000 L of organic fertilizer per month. Assuming that the total needs of fertilizer per year needed in university is 48,000 L per year, taking as an assumption that there are 4 hectares of green areas that need to be fertilized; there is a remaining of 65,100 L that can be sold. On the market, 8 L of bio fertilizer cost 27,000 COP, consequently the revenues obtained for the selling of the fertilizer could be up to 219,712,500 COP.

Total savings are estimated at 48,333,527 COP. But this doesn't include the hypothetical possibility of selling the produced organic fertilizer, because the mission of the university doesn’t include selling of tangible and agricultural products. However it can be considered to distribute this remaining fertilizer with other companies who are already in the agro market.

Table 17 shows the financial evaluation of the tubular Biodigester BB40 installation. The project will be economically viable by year 2022 (i.e. return of investment in less than 4 years. The IRR for this project is 28.21% and the VPN for year 2033 is 219,928,741 COP, which represents the savings for this year. The model assumes that the wage of the new hired and the water consumption costs are the same for all of the years.

Financial Costs			
Item	Estimation Method	Key Assumptions	Value per year
1.Biodigester BB40	Price obtained directly from supplier	Biodigester model used for the study is Biobolsa BB40.	$ 9,163,000.00
2. Biodigester transportation to ICESI	Provided by supplier (validated by three higher)	one Biodigester transported on a m heavy duty vehicle	$ 550,000.00
3. Water Usage	Provided by Emcali	2:1 relation with Aguamasa	$641,634.29
4.Installation Cost			
4.1 Civil construction			
Hole Excavation	Cost of labor: shadow wage rate [minimum wage x estimated time based on previous installations]	University employees dig and prepare the hole.	$ 211,121.50
Ground preparation	Cost estimates provided by the physical plant department from Icesi University	Biodigester installed in Casa Almadiana	$ 95,000,000.00
Backfill			
Plumbing			
6. Repair and Maintenance Costs	Obtained directly from supplier	Users abide by general guidelines of use as per training.	$ -
7. Training and technical assistance	Estimated by supplier, who provides training	Local resident will provide training to users	$ 1,000,000.00
8. Biodigester feeding	Cost of labor: minimum wage	New employee	$ 12,667,288.44
		Total Life Cycle Costs	**$ 119,232,644.23**
Financial Benefits			
1.Avoided Natural Gas Cots	Market prices of estimated Natural Gas savings.	Biogas will replace part of other cooking fuels on the campus	$16,509,526.54
3. Avoided Incineration Costs	Market price of Incineration services	$600/KG	$31,824,000
4.Selling the remaining Biol (produced fertilizer)	Market price of Biol (produced fertilizer)	Bioslurry will produce additional income if sold	$219,712,500
		Total Financial Benefits	**$ 268,046,026.54**

Table 166: *Financial costs and benefits*

NET CASH FLOW					
	2018	2019	2020	2021	2022
Net Utiliy	$0	$48,333,527	$48,333,527	$48,333,527	$48,333,527
EBITDA	$0	$47,775,377	$47,775,377	$47,775,377	$47,775,377
1. Net Period Cash Flow	$0	$47,775,377	$47,775,377	$47,775,377	$47,775,377
2.Investment	$119,232,644	$13,309,288	$13,309,288	$13,309,288	$13,309,288
3.Net Period Investment	$119,232,644	$13,309,288	$13,309,288	$13,309,288	$13,309,288
4. Net Cash Flow	-$119,232,644	$34,466,088	$34,466,088	$34,466,088	$34,466,088
Net balance	-$119,232,644	-$91,682,049	-$62,533,520	-$31,694,376	$933,438

Payback	3.97
IRR	28.21%
NPV	$219,928,741
Mininum return rate	5.80%

Table 177: *Financial Evaluation*

Critical Activity 3.2 (CA 3.2): Consider space and environmental impact

The data from the month of May it is the average daily value of the calculated results CA 1.2 multiplied by the work days in that month was used, with the exception of the months of June and December that used half of the work days due to the vacation period in this month.

	Cafeterias' Waste (ton)	Incineration (ton CO2 eq)	Landfill (ton CO2 eq)	Work days in that month
Kg CO2 equ/Kg	N.A	0,021	0,57	N.A
January	2,83	0,06	1,61	21
February	2,87	0,06	1,64	25
March	3,50	0,07	2,00	21
April	3,38	0,07	1,93	26

May	3,76	0,08	2,14	24
June	1,96	0,04	1,12	13
July	3,76	0,08	2,14	24
August	4,08	0,09	2,32	26
September	4,08	0,09	2,32	26
October	3,92	0,08	2,23	25
November	3,76	0,08	2,14	24
December	1,96	0,04	1,12	13
TOTAL	**39,86**	**0,84**	**22,72**	**268**
TOTAL CO2 EQ				

Table 18: *Current emissions from cafeteria waste*

The waste of the cafeteria and from this waste were estimated two emission factors at the end of life. The first one is the incineration that has a factor of 0.021 Kg CO2 per Kg of waste, this was calculated because the university shows that it pays for this service, however the reality is that the waste is taken twice a week by third parties to be used on farms, this fact leads to these wastes are considered as waste in landfills which has a factor of 0.57 Kg CO2 per Kg of waste.

It can be seen in table 20that the change in CO2 equivalents is almost 22.72 tons. Finally the tons of CO2 equivalent from the incineration were not taken into account in any part of the analysis because this final provision is never used, it is only reflected in the financial costs of the university.

CONCLUSIONS

There was some already collected data of organic waste in the university. This data was collected for year 2016, from all the green trash bins in the university with the tag organic and ordinary. This data was useful to create a general idea about the seasonal variations caused by the vacation period. This variation shows that the production of June of organic and ordinary waste diminishes up to 50% the monthly average production, and a similar trend was observed with Aguamasa. However it is important to clarify that this mixture of residues is not ideal to use in a biodigester, due to a reduction in process efficiency, and this is the reason why it is not included in the technical study. Nevertheless, 4.8 tons/month of organic and ordinary waste, shows a big potential for further attempts in creating a culture of separation in which the university can use the organic percentage of this waste in the anaerobic process.

The core contribution of this study was the estimation of food waste (aguamasa) that the university produces and disposes as organic waste. Due to the fact that this organic waste is disposed as only Aguamasa, was considered for the technical and economic study. In average, the university produces 1.05 tons/week. This waste comes from the two principal cafeterias on the campus. Likewise, the university, due to its approximately 4 hectares of green areas, produces yard waste, which was not taken in account for the study, because it's larger digestion time.

Biomethane potential was calculated in another ongoing thesis of the university. The most important results from this study are: average percentage of volatile solids in Aguamasa 20.22%, average Biogas potencial 625.49 m^3 of biogas/ Ton of Volatile solids, and CH4% is 63.47%. Estimation of Average monthly Biomethane production is 337.039 m^3 and annual Biomethane production is 4044.37 m3.

The financial evaluation of the tubular Biodigester BB40 installation shows that the project will be economically viable by year 2022 i.e. that the payback is 3 years and 11 months assuming a time horizon of 15 years. The IRR for this project is 28.21% and the NPV for year 2033 is 219,298,741 COP, which represents the savings for this year. The model assumes that the wage of the new hired person and the water consumption costs are the same for all of the years**.**

The environmental impact with the implementation of the biodigester is positive and this can be reflected in a 42.7% decrease in the emissions caused by this waste. It should be noted that these calculations are only related to the waste of the cafeterias and not to the total equivalent of tons of CO2 generated by the University.

This reduction of 22.72 in its emissions equivalent to CO2 in the organic waste from cafeterias, which translates into a decrease of 64 SamaneaSamán type trees which has 36 years old, 124cm DBH (Diameter at Breast Height) and 15 meters high to sow to offset these emissions, in addition to this it was seen that this project can be an academic sample that will allow students to have an approach to the reality of the theory seen, apart from promoting this type of projects in the university community.

RECOMMENDATIONS TO UNIVERSIDAD ICESI AND ITS COMMUNITY.

It was observed that in spite of measuring the waste mix, in which organic and inorganic materials are concentrated, it is possible to rescue useful organic materials to feed the biodigester, it is suggested to the university to carry out education campaigns towards the correct disposal or to separate organic foods into the garbage cans in a more efficient way, this in order to reduce costs, increase the production of biogas, fertilizers and reduce the impact of the ecological footprint, these is an invitation to continue the investigation of how to achieve this efficient way in order to obtain all the benefits that these organic waste provide to the university community, with an integral commitment to the environment.

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