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Alternative Form of Clean Energy Generation: The Creation of Autonomous Units of Power Generating Biodigester Systems

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***Abstract*-** Small scale power generation facilitates turning waste products into energy for domestic uses. This is a viable option for rural areas, as it creates employment and have less harmful environmental impacts. The aim of this project was to study the potential of turning small scale biodigester byproducts into clean energy in a small rural area in Brazil. The viability of this concept was evaluated by conducting surveys locally and compiling data on all aspects of the operation (e.g. supplies, construction and maintenance). Results support the feasibility of these systems to generate energy for household uses while decreasing CO_2 emissions, curbing deforestation and reducing waste streams.

***Keywords*-** *Energy Security, Sustainability, Biodigester Systems, Clean Energy, Small Scale Energy Generation*

I. INTRODUCTION

Large-scale power generation sources, such as coal, gas and nuclear energy, have shown to be detrimental to the environment. These forms of energy generation are also very expensive, since they require substantial investments in infrastructure as well as in distribution lines to reach the consumer. Fortunately, consumers located far from the generating plants, have in most cases the possibility to generate their own energy from natural sources such as wind, sunlight, algae, garbage and human or animal waste. These alternative sources of energy could provide them with all, or part of the energy required, and the excess energy could still be shared with others in the community. In this context, energy production is cleaner than large-scale production systems as impacts, including long-term maintenance, are limited. Small-scale power generation systems in poor rural communities could also help improve the environment and public health as human waste usually released in the environment could be turned into energy for either electricity generation or heat for cooking. An additional benefit to rural communities would be the generation of a new source of income through fertilizer production from waste byproducts.

Studies on small scale energy generation have given rise to alternative ways of producing clean and renewable energy with an equal or lower cost than conventional methods. They have also helped to identify major bottlenecks in energy production regarding technical and public policy aspects. In addition, these studies have proved the relevance of small-scale energy generation systems in helping rural communities producing their own energy and fertilizer, saving money and protecting the environment; ultimately, this has the potential of transforming their own economic reality. The actual state of the world economy and resources used by poor people to generate heat and electricity, such as woody biomass, cause devastating effects to the environment and to public health [1]. Thus, small scale power generating systems represent valuable options that address these issues and allow these communities to live better, and with attenuated risks of diseases.

One of these communities is found in the river island of Nhamunda in the Northern region of Brazil, in the state of Amazonas (fig. 1). The island produces a boat load of garbage waste each day (fig. 2), while electrical power is generated by a thermal power plant powered by diesel fuel (fig. 3). In addition, the island does not have any sewage treatment plant (fig. 4), therefore human waste is dumped directly untreated into the river, polluting its waters and causing epidemic diseases seen nowhere else.

Figure 1. Aero view of Nhamundá Island

Figure 2. Boat of garbage produced in Nhamundá Island

Figure 3. Thermal power plant powered by diesel fuel

Figure 4. Open-air Sewage

Addressing these issues would seem to be a no brainer, as the island produce enough wastes to power an electrical plant while reducing pollution, diseases and protecting its environment. But why is it not being done? Could it be a lack of knowledge or public policy? Similar questions were raised by Mohtasham [2], who reviewed the pros and cons of few common renewable energy systems [2]. His findings have served as a reference and contributed to build this work. According to the author, it is almost impossible to convince people to give up their traditional source of energy (fossil fuels) and adopt renewable sources, as these traditional sources are well established and convenient for users. However, he concluded that, it is extremely urgent and necessary that scientists keep communicating the pro-arguments to the public to ease-up the transition process, while lobbying governments to enact proper policies promoting the wide adoption of renewables. Increasing renewable energy production could promote economic growth in poor communities.

According to Saidi and Hammami [3], economic growth is tightly linked to energy consumption and the concomitant CO_2 emissions. The former is considered a bottleneck when it is lacking or poorly planned, while the later constitutes an ever-increasing issue when economic growth develops in a disorderly manner. The authors showed that "the effect of economic growth and CO_2 emissions on energy consumption is positive and statistically significant on a global scale". These findings implied that "economic growth, CO_2 emissions and energy consumption are complementary". In other words, the relationship between economic growth, CO_2 emissions and energy consumption implies that when for example food consumption increases in an area, so does production on an either large or small scale. For large scale food producers, access to modern technologies and capital are the main drivers, when it comes to using by-products to produce gas and fertilizer. Preserving the environment is usually an afterthought. For small food producers, however, the realities are different. Their need for technological knowhow is crucial if they are to make better use of by-products from their production.

Latin America and the Caribbean region is one of the main producers of food in the world and as such, is now confronting with a whole host of environmental issues. These problems brought about by waste disposal and the burning of materials to generate electricity and heat for homes, seem to have worsened the negative impacts of global warming. This has recently brought the attention of the United Nations (UN) which has well-founded concerns about energy generation in the Americas. One way to circumvent these environmental issues, according to the UN, is to look for ways to transform agricultural, industrial or domestic wastes, sunlight and wind into usable products. By doing so, not only the harmful effects caused by conventional energy sources would be eliminated, but also a new stream of income would be provided, since new sources of sustainable energy would be developed.

In Kebreab *et al.* [4], the authors reported on technological innovations in animal production as they relate to environmental sustainability. These innovations targeted the mitigation of environmental pollution, while increasing sustainability of animal production and conversion and use as an energy source. A specific generator device was highlighted as one of the possible alternatives to reduce the emission of aggressive gases in the atmosphere. These gases and the heat arising from manure burning in anaerobic digesters have been used for electricity generation. Rowse [5] however, stated that small-scale anaerobic digesters can only be used for heating, cooking and lighting [5]. Electricity generation from anaerobic digesters can only be performed with the use of large-scale biodigesters, due to the amount of material needed. Thus, if the target is electricity generation, any proposal should consider a consortium of farms producers or village residents capable of supplying large amount of organic material and build a larger and long-lived anaerobic digester.

Such an initiative is currently ongoing in Brazil, promoted by the biggest energy producer, Binacional Itaipu, a hydropower company. The company built a network of 33 small anaerobic biodigesters in rural communities, connected by 22 kilometers of pipeline to a thermoelectric power plant, which supplies energy back to these communities in the form of biogas. This is a promising alternative for poor communities not only in Brazil but around the world, since it has been estimated that more than two billion people don't have access to clean, safe and sustainable energy and their energy supply is based on available sources and what their knowledge allows. As a result, these people often burn firewood or dried animal feces for cooking, heating and fossil fuel for lighting or electricity generation. These energy sources have serious negative environmental, health and economic impacts [6]. Biogas resulting from anaerobic digesters could provide an affordable, clean and reliable alternative source of energy, as just 25kg of animal waste per day can replace 5kg of firewood, 1.5kg of charcoal or 0.6 liters of mineral fuel per day. In addition, the generated effluent or bio-slurry can be transformed into a high-quality bio fertilizer. Fertilizers generated as byproducts of anaerobic digestion, have demonstrated to improve crop productivity tremendously, and FAO has given it a value equivalent to Gold. These findings were confirmed by Hilbert [7] who stated the unloading of such digesters must occur twice per year and the user must schedule it for the new crop-planting season, so they can use the bio slurry collected as a fertilizer to improve the productivity and the quality of crops. According to the author, one cubic meter of biogas can operate several devices, thereby saving money for the consumers. Figure 5 illustrate some possible uses of a cubic meter of biogas.

Figure 5. Some of the applications of 1 m^3 of biogas

Anaerobic digesters have shown tremendous benefits to communities adopting this kind of technology. When rural communities in developing countries develop small-scale anaerobic digesters, the positive impacts are as follow, according to Rowse [5]:

- energy production in the form of methane, which can be used for cooking, lighting or heating fuel;
- elimination of indoor air pollution (that results from people burning wood or charcoal inside their homes);
- reduction of unsustainable deforestation due to collection of wood for use as a biomass cooking or heating fuel;
- mitigation of methane and black carbon emissions into the atmosphere;
- treatment of animal and/or human waste;
- reduction of the amount of bio solids to be disposed;
- production of nutrient-rich effluent that may be used as fertilizer;
- reduction of the costs of cooking, lighting or heating fuel;
- saving or making money by using or selling the fertilizer.

Furthermore, several feedstocks can serve as feeding material for anaerobic digesters, which can be grouped into three groups[8] (Fig. 6).

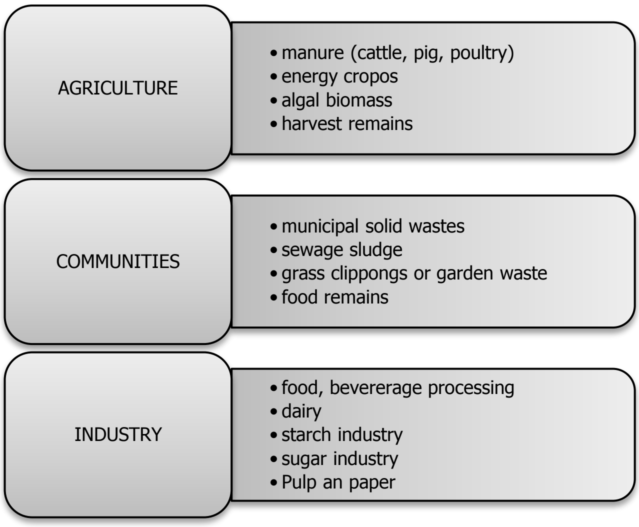

Figure 6. Sources of feedstocks for anaerobic digestion (adapted from: Steffen *et al*. [8]

The aim of this research was to investigate potential alternatives of generating sustainable clean energy at small scale from biodigester systems, with a focus on the viability of these systems to create employment in poor communities. A second aim was to conduct a survey on the best practices to develop effective clean energy at small scale by biodigester systems and determine the economic impacts of such systems in the generating units and public policy for power generation. Specifically, this research sought to answer the following questions: 1) What are the possible alternatives for clean energy generation by biodigestion on a small scale for personal use? 2) How to choose the best alternative based on the characteristics of each biodigesting unit? 3) What are the costs (investment and maintenance) involved in generating energy via anaerobic digester devices?

II. MATERIALS AND METHODS

The methodology for this research follows the procedure published in de Andrade Marconi & Lakatos [9]. To properly investigate and analyze already published data, which are at the basis of this study, the following steps were taken:

- Identification of the theme;
- Bibliographic review;
- Selection of relevant materials;
- Organization of the work structure;
- Data evaluation and synthesis of knowledge gained.

In addition, a thorough search over the World Wide Web was conducted with the following keywords: clean energy, renewable energy, anaerobic digester, human waste, food waste, animal waste, sewage waste, and biogas. If any of those keywords was present in the title, keywords or abstract, the work was considered. This work inquired websites and stores searching for specifications and pricing of components needed to build the anaerobic digester. A fieldwork methodology was adopted for this study, where surveys were conducted, or data collected systematically where the work is most likely to be performed. During this work, a table of contents with a description of the material and amount was generated[9]. To generate this list, two physical stores were visited, and prices were recorded. The consulted stores are referenced in the bibliography section of this work.

III. RESULTS AND DISCUSSION

The findings here outline a proposal on how to build a low-cost digester. Via a social technology, we can demonstrate how to build an artifact that aims at converting organic material into energy for heating, lighting or cooking. To produce electricity, it is necessary to connect multiple artifacts together to generate the large amount of gas required to power the generator. An extensive literature review served as the basis of our construction and conclusions. [7,8,10,11,12,14,15,16,17,18,19,20,21]

Figure 7 represents a drawing of the artifact. It was used to facilitate the understanding of the construction process. This drawing features a fixed amount of manure mixed with a fixed amount of water being fed into the digester once a day. Let us suppose that the manure comes from a small farm that has 20 livestock: 10 cows and 10 pigs. Each cow weighs approximately 350kg and each pig weighs 65kg. As demonstrated in Cedecap [12] and Lüer [17], this type of anaerobic digester is a so-called semi continuous Polyethylene Tubular [12, 17]. This is one of the most useful and cheapest digesters one can build and it is also commonly found in rural areas. To build this kind of digester, it is necessary to dig a trench big enough to store the waste, the water and the gas. The digester is loaded every day by gravity with the waste and water mixture and after the retention period, it produces a continuous amount of gas per day. Figure 7 shows a draft of a trench design with its main measurements.

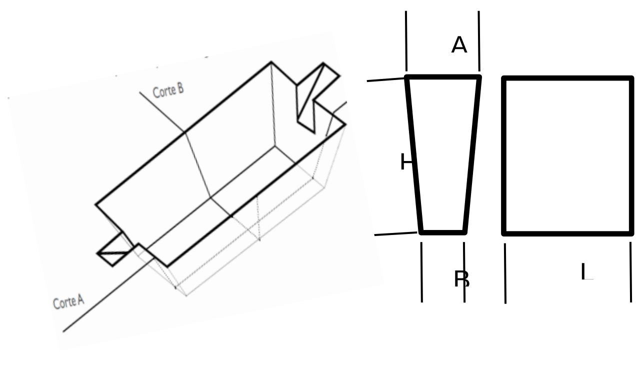

Figure 7. Draft draw of a digester design [16]

In the first step, we calculated the size of anaerobic digester. One of the input data, was the amount of waste produced by these animals. According to Herrero [16] and Steffen [8], a cow produces 8kg of waste for every 100kg of its weight, while a pig produces 4kg for every 100kg. Therefore, 10 cows and 10 pigs are expected to produce 280kg and 26kg respectively. When the cows are not confined, only 25% of this value can be accounted for (70kg/day). If confined however, 50% of the waste can be captured. As for the pigs, each one can produce 2,6kg a day (0,65 X 4) which amount to 26kg total [18]. So, the total amount of animal waste is 96kg, which is equivalent to 96 liters. Based on these number, one can scale up the size of the anaerobic digester. This can be done according to CEDECAP [12], who showed that it takes one part of waste to four parts of water (25%) to store the gas. This is illustrated in figure 8.

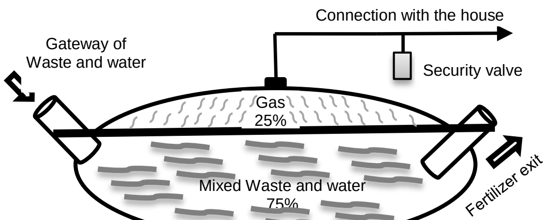

Figure 8. Illustration of an anaerobic digester process (adapted from Herrero [12]).

In the example given above, for 96 liters of waste, one needs to add 384 liters of water (96 X 4) which equals to 480 liters per day. Given an average temperature of 20^{o}C, the hydraulic retention time (HRT) is 25 days. To calculate the entire volume, one needs to take the daily volume (480L) and multiply it by 25 days = 12000 liters, then add the volume of gas (12,000 + 4,000 = 16,000 liters). If 16,000 liters represent 100%, then 75% is equal to 12,000 liters (waste plus water) of which 25% or 400 liters (16m^3 cubic meters) represents the gas. With the volume of the trench, one can now calculate the main measurement of the digester (A, B, H and L in figure 7). Usually it is possible to buy the polyethylene plastic roll tube in the following widths: 1 meter, 1,25 meters, 1,5 meters, 1,75 meters and 2 meters. Herrero (2008) (16) recommended to build a table with those five possibilities and adopt that one rate between the length and the diameter between 1:7 and 1:8. Table 1 is showing the best way to build the device.

TABLE I. CALCULATIONS FOR FIND THE BEST RATE (L/D) TO BUILD A DIGESTER

Width roll (m)	Radius (m)	Diameter (m)	Area (m^2)	Length (m)	Rate (L/D)
1	0,3183	0,6366	0,3183	50,2656	78,9572
1,25	0,3979	0,7958	0,4974	32,1700	40,4261
1,5	0,4775	0,9549	0,7162	22,3403	23,3947
1,75	0,5570	1,1141	0,9748	16,4133	14,7325
2	0,6366	1,2732	1,2732	12,5664	9,8697

In Herrero's study [16], a trench was built with the following dimension: A= 2 meters width, B= 3 meters width, H= 2 meters high and L= 12,5 meters length. The amount of biogas produced per day was calculated by first finding the mass of volatile solids (VS) loaded into the reactor in a daily basis. To do so, one needs to consider the amount of waste produced by the livestock and then find the percentage of volatile solids in the waste (VS%). The total solids, according to Steffen *et al* (1998) and Buxton and Reed (2010) for the cows and for the pigs are respectively 12% and 8%, and the percentage of VS is 80% for the cows and 75% for the pigs[8,11]. Table 2 shows how much biogas is possible to produce a day with the amount calculated in this example.

TABLE II. TOTAL AMOUNT OF BIOGAS PRODUCED PER DAY

Description	Cow	Pig
Amount of waste per day (K)	70	26
% of solid waste	12%	8%
Solid waste per day (K)	8,4	2,08
% of volatile solids (VS)	80%	75%
Volatile solids per day (K)	6,72	1,56
M^3 of biogas per K of VS	0,25	0,38
M^3 of biogas per day	1,68	0,59
Total estimate amount of biogas per day in our example = 2,72 M^3		

As showed by Hilbert [7], a kitchen burner uses between 300 to 600 liters of biogas per hour or 0,3 – 0,6 m^3 per hour, which amounts to 2,72 cubic meters[7]. Even in the worst-case scenario, one can keep a burner working for 4 hours and 30 minutes, time enough to cook at least two meals a day. Hilbert [7] stated also the one mantilla light spends from 120 to 170 liters of biogas per hour or 0.12 – 0.17 m^3, which can light a 60W lamp for 16 hours per day or four lamps for 4 hours per day[7]. In comparison, a cooktop stove powered by propane spends roughly 65,000 BTU/hour which represents 5 to 10 gallons per month, enough fuel to cook two meals a day. The price of propane gas from Ferrellgas Company in the USA as of January 2017, was US$2,149 per gallon. The cost of propane gas for a family with a medium consumption of 7,5 gallons a month, is then about US$ 2,149 X 7,5 = US$ 16,12 a month. In this case, if a family in USA uses a digester, they could save roughly US$16,12 a month. And since the device costs US$ 354,87, the payback time or return in investment will occur in 22 months. Fig. 9 shows the estimated costs of material needed in the USA to build an anaerobic digester.

Fig. 10 shows the auxiliary costs to build an anaerobic digester, but if some of these resources are already available, the respective auxiliary costs could be cut. Frequently the owner of the property will dig a trench and assemble an artifact using his owns tools with the help of neighbors or family, thus these costs will be non-existent.

Description	Unit	Amount	Unitary Cost	Total Cost
Tubular Polyethylene - 300 microns - black smoke (UV-filter) width of roll = 2 meters	mts	14	$ 2,80	$ 39,20
Tubular Polyethylene - 200 microns - transparent width of roll = 1,0 m	mts	8	$ 2,65	$ 21,20
Tubular Polyethylene - 250 microns [□m] - transparent width of roll: 2,0 m	mts	9	$ 2,65	$ 23,85
PVC drainpipe - 6" and lenght = 1 meter	mts	2	$ 21,24	$ 42,48
Rubber strap - produced from old automobile tire-tubes 4 - 5 cm width	mts	60	$ -	$ -
PVC tube bend ½ll	unit	4	$ 0,48	$ 1,92
PVC T-fitting ½ll	unit	4	$ 0,73	$ 2,92
PVC lock valve ½ll	unit	5	$ 2,69	$ 13,45
PVC universal coupler ½ll	unit	2	$ 0,65	$ 1,30
PVC adapter flange ½ll	unit	3	$ 31,00	$ 93,00
PVC - tube ½ll (irrigation tube)	mts	9	$ 1,65	$ 14,85
Teflon tape	unit	2	$ 1,47	$ 2,94
PVC plug for T- tube ½ll	unit	1	$ 0,96	$ 0,96
Tarpaulin (4 m x 9 m)	unit	2	$ 39,98	$ 79,96
Steel wool (SH4 filter)	unit	1	$ 1,00	$ 1,00
Transparent flexible tube (to level the inlet and outlet tubes) ¼ll - ½ll	mts	12	$ 1,32	$ 15,84
Total cost of direct material				**$ 354,87**

Figure 9. Budget to assembly a small anaerobic digester in USA

Description	Unit	Amount	Unitary Cost	Total Cost
Biogas - burner	unit	1	$ 27,45	$ 27,45
Biogas - lamp	unit	1	$ 8,00	$ 8,00
Shear	unit	1	$ 10,97	$ 10,97
Measuring tape 8 m – 10 m	unit	1	$ 25,47	$ 25,47
Saw	unit	1	$ 4,96	$ 4,96
Pipe tongs	unit	1	$ 13,68	$ 13,68
Pipe tap ½ll for outside thread	unit	1	$ 1,00	$ 1,00
Screw driver	unit	1	$ 5,97	$ 5,97
Hand Labor 8 hours a day = 8 X US$15.00	unit	2	$ 120,00	$ 240,00
Total cost of auxiliar material				**$ 337,50**

Figure 10. Budget for auxiliary material to assembly a small anaerobic digester in USA

IV. CONCLUSIONS

As demonstrated, anaerobic digestion appears to be a feasible mechanism to generate energy, whether it is for heating, cooking, lighting or electricity generation. It is also a great approach to help the environment by decreasing CO_2 emissions, avoiding deforestation and properly treating the generated wastes. Ultimately, this concept of energy generation leads to improvement in human health and increases the quality of life. Our objective to investigate potential alternative way of generating sustainable energy at a small scale seems to have been met. In addition, we could demonstrate best management practices to develop effective clean energy generation at a small scale. Families that adopt this type of technology can be economically positively impacted, thereby improving their quality of lives. Even when the gas is not a main target as shown in Bolivia [22], the byproduct resulting from the anaerobic process is a motivating factor to keep the artifact working.

Maybe a saving of US$ 16,00 a month is not a big deal for an American family, but for a family that does not have a reliable source of energy or instead must struggle to find energy for cooking, heating or lighting, it is going to be a good deal. Furthermore, the byproduct used as a natural fertilizer, can help families increase their income by either selling or using this organic material. For example, fertilizing $100m^2$ of corn costs US$ 150,00 per acre [23]. This money could be saved by using the digester bioslurry in place of a commercial fertilizer. This saving reduces the pay back from 22 months to 12 months if the fertilizer is applied only once a year. Warnars & Oppenoorth [6] indicated that the bioslurry has the potential to improve soil fertility and soil structure, increasing cereal crop productions by 10 to 30% and working as a plague repellent as well. They described the following advantages when somebody uses a bioslurry as a fertilizer:

- Increase in soil fertility (caution exchange capacity), and better soil structure and water holding capacity.
- Decrease in soil erosion.
- Higher germination rate of seeds, disease resistance, better yields, improved coloration of fruits and vegetables, and tenderness and taste of leafy vegetables.
- Increase in the feed value of fodder with low protein content.
- Increase in the production of earth worms and algae.
- Higher quality and quantity of organic grown flowers and vegetables.
- More availability of nutrients for soil micro-flora (e.g. nitrogen and phosphorus).
- Reduced use of phosphates, a non-renewable source which is being depleted globally.
- Reduce wastewater, water pollution, greenhouse gas emissions and noxious odors.
- Reduce weed growth and attractiveness to insects or flies.

Ultimately, we could address the three initial questions: 1) there is an alternative way for a small unit to generate its own power needs; 2) We demonstrated how to size an anaerobic digester according to the characteristics of one simulated unit; 3) Costs analysis involved in generating energy via an anaerobic digester device showed the guaranteed payback time, validating it from the economic point of view. These findings can motivate further public policy addressing the needs of energy generation at a small scale while helping environmental preservation.

In this study, the focus was on small agricultural producers and the utilization of livestock waste to produce energy. Further investigation should consider domestic organic waste (e.g. human sewage and food scraps) and determine how they could feed an anaerobic digester and their performance to generate power. Another line of research could focus on bibliometric analysis, doing a systematic replication based on Wang's article [25]. The period covered by this author (i.e. 1994-2011) could be extended to include 2012 to 2016 by making a comparison between the results of both studies. Findings from this research could increase internal and external validity of this field of research and reveal how the academic research evolved throughout the years. Finally, we hope that adoption of sustainable practices of power generation are encouraged by governments through public policies or by the non-governmental organizations, by facilitating educational programs in workshop formats to teach communities how to build and manage an anaerobic digester.

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