Fall 2014

The Mechanical and Social Feasibility of Using Biogas to Fuel an Essential Oil Distillation Unit in the Rural Commune of Ankarimbelo, Madagascar

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SIT Study Abroad

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To Madagascar, this land, and these people: I carry you with me.

Contents

Abstract

The rural commune of Ankarimbelo is located on the edge of the Ikongo Rainforest Corridor in southeastern Madagascar. The commune's remote location, an increasing population, and the prohibition of farming in the rainforest corridor have contributed to extreme poverty. In an attempt to mitigate these effects, the Malagasy NGO Ny Tanintsika has implemented an essential oils distillation plant as an alternative livelihood project. While the project may provide needed income to local populations, thereby diverting destructive agriculture practices such as *tavy*, or slash-and-burn agriculture, the distillation of essential oils still requires that firewood be burned. Over the course of one year, between 700,000 and 111,000 kilograms of wood could be consumed. While Ny Tanintsika is investing in a sustainable Eucalyptus plantation in the commune, establishing a biogas plant as an alternative fuel source could benefit the local environment and population. This study evaluated the mechanical and social feasibility of using biogas at the essential oils plant. In particular, it determined the proportion of the energy demand that biogas produced from local biomass sources could meet. The results indicate that in the extreme case in which the still's energy demand is maximized and biogas production is minimized, biogas could meet 4% of total energy demand. However, in less extreme cases, in which biogas production is larger or still energy use is less, biogas may be able to meet most or all of the energy demand. Moreover, the local population supported the creation of a biodigester.

I. Introduction

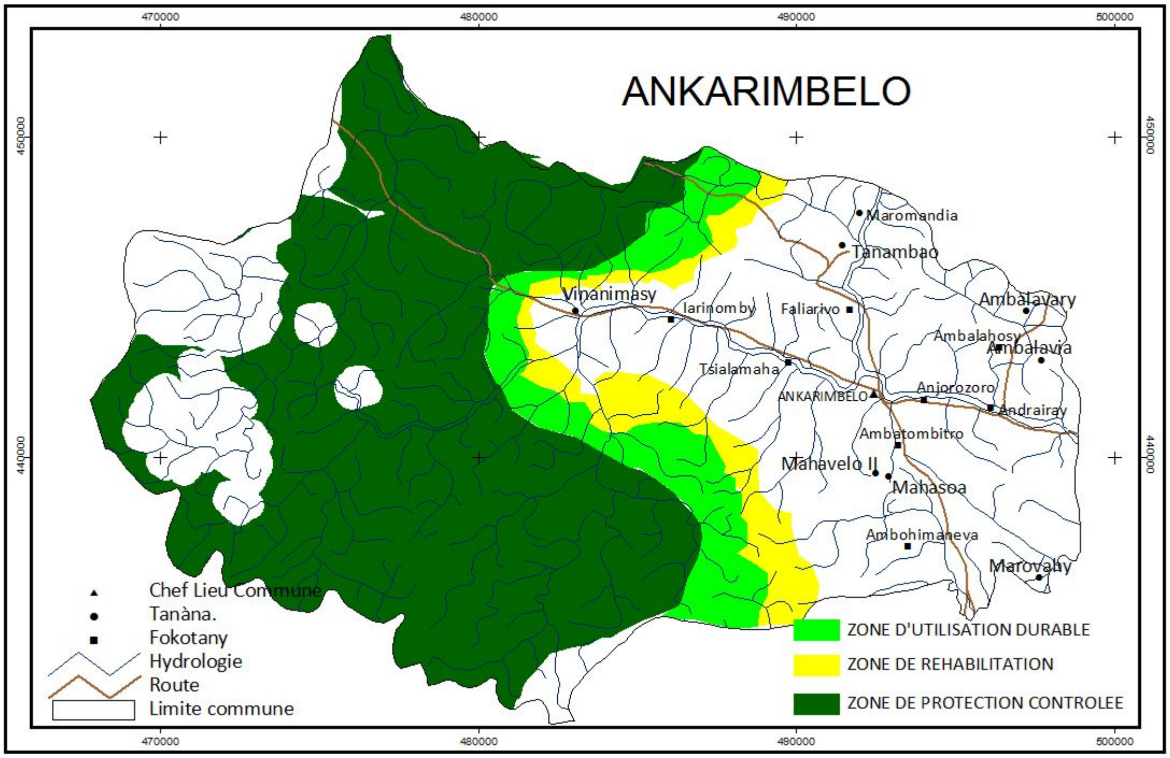


Figure 1: Ikongo Rainforest Corridor and the Rural Commune of Ankarimbelo
Source: Ministère 2009

Faliarivo is a village in the rural commune of Ankarimbelo. The village, which is predominantly inhabited by individuals of the Tanala ethnic group, is located at the base of the escarpment that divides the Southern highlands from the east coast of Madagascar. The village is also located at the edge of the protected area of the Ikongo Rainforest Corridor [figure 1]. Faliarivo is accessible by foot and road. However, the road is frequently impassable. Cars attempting to make the journey must bring materials to cross multiple rivers. The footpath traverses the highlands south of Ambohimahamasina, crosses the rainforest corridor, and descends into the valley where the commune is located. The path takes between 9 and 12 hours to complete, and it is estimated that it is between 35 and 40 km (21 and 24 miles) long. Men from the rural commune frequently complete the trip carrying two jerry cans filled with *toaka* *gasy*, or traditional Malagasy rum, on a bamboo pole balanced on their shoulders, while women carry baskets and bags filled with fruit or other goods on their heads. Anything that the people of the village are unable to grow and produce in the valley must be carried from Ambohimahamasina.

As a result of the remoteness of the village, the people of Faliarivo rely on agriculture both as a source of food and cash crops. Agriculture in the commune of Ankarimbelo is dominated by rain-fed rice and cassava, occupying approximately 50% of all cultivated land. Cassava fields alone occupy over a quarter of farmed land. To prepare the steep hillsides for the cultivation of cassava, farmers use *tavy*, or slash-and-burn agriculture. While *tavy* clears the land of unwanted plant matter with minimal effort, the resulting soil has limited fertility. Once the limited nutrients are expended, the field must lie fallow for one to five years before the health of the soil is restored (Ministère 2009). Due to the continual depletion of soil resources, farmers seek new farmland, where they employ *tavy* once again. The process repeats, resulting in the cyclic destruction of indigenous habitats and biodiversity.

The destruction of forest habitats is further exacerbated by the use of forest resources for firewood, construction, and carpentry. In the commune of Ankarimbelo, each household consumes an average of 27 m^3 of firewood each year, resulting in a total annual consumption of over 67,000 m^3 of firewood. In total, over 28 ha are degraded each year as a result of the use of firewood. An additional 38 ha are degraded by the consumption of construction wood (Ministère 2009). In total, approximately 65 ha of forest are degraded each year.

The Ikongo Rainforest Corridor was created in part to protect the unique forest resources, habitat, and biodiversity from *tavy* and the collection of firewood. For the most part, the corridor has protected the forest. The community of Ankarimbelo has, in general, respected the protected area since its creation. However, the corridor limits the land which is available to the people of Faliarivo for agriculture and the harvest of forest resources. The effects of this limitation are further exacerbated by continuing population growth. From 2003 to 2008, the population of the *fokontany*, an administrative district, almost doubled, increasing from 10,400 to 20,300 (Ministère 2009). Without sufficient farm land, the growing population faces increasing problems. According to the *chef fokontany* of Faliarivo, the resulting hunger has resulted in increased theft by hungry youth.

The Madagascar NGO Ny Tanintsika (Our Earth) works to address these and other problems in Faliarivo by creating an alternative livelihood for community members. The NGO, which was created with the assistance of the Scottish charity Feedback Madagascar, works to "alleviate poverty through an integrated approach, recognizing the inter-relationship between poverty, environmental degradation and poor health" ("About Us" n.d.). Their work also emphasizes the importance of local involvement and leadership in the creation and implementation of projects.

In Faliarivo, Ny Tanintsika worked with community members to establish an essential oils plant. The base community (*communauté de base*, or COBA) cultivates Ravintsara (*Cinnamomum camphora*), a plant endemic to Madagascar, for the production of essential oils. Ravintsara essential oils are used in the treatment of viral infections of the respiratory, digestive, and urogenital systems. It is also an immune-stimulant, bactericide, and antiseptic ("Ravintsara" n.d.). The distillation requires between 200 and 250 kg of ripe Ravintsara leaves. The leaves are dried in shade for twelve hours before being placed in the still. In the still, steam is used to release the essential oils from the leaves, which is condensed and collected [figure 2]. The 2.5 to 3 hour distillation requires between 0.35 and 0.5 m^3 of wood. If four distillations were completed a day, five days a week, for the duration of the six month Ravintsara season, the still would consume between 175 and 275 m^3 of wood.

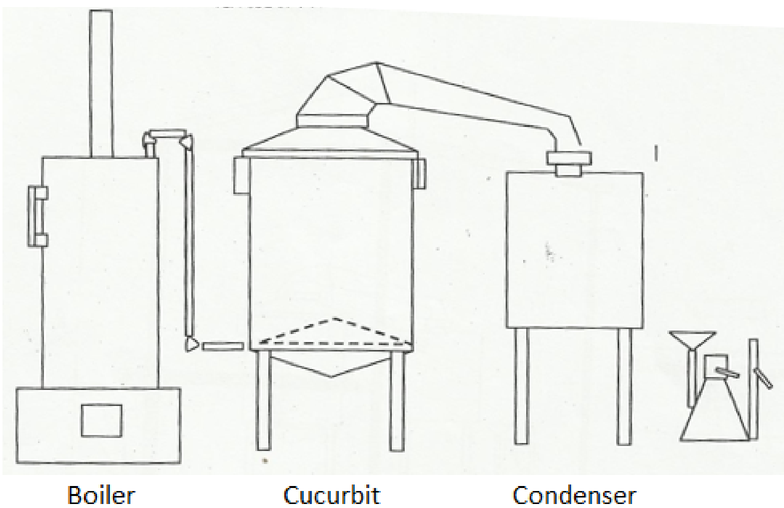


Figure 2: A steam distillation unit
Source: Feedback Madagascar Internal Documents

The still currently has access to a source of sustainably cultivated and harvested wood, and Ny Tanintsika is investing in a long-term project to establish a sustainable Eucalyptus plantation to provide wood for the still. Despite these sustainable sources of firewood, establishing an alternative fuel source could have several sustained benefits. First, it would reduce short- and medium-term pressure on forest resources while the Eucalyptus plantation continues to be established, further safeguarding the surrounding land. Second, the implementation of an alternative fuel source could provide a precedent for other essential oil projects, especially those located in regions less able to establish sustainable wood plantations.

Biogas is a promising alternative fuel source which has the potential to either supplement or replace the firewood used to heat the essential oils still. Biogas is a renewable form of energy which utilizes the gaseous byproducts of the anaerobic decomposition of biomass, or organic materials. Liquid, homogenized biomass is placed in a biodigester where it is allowed to decompose. In anaerobic, warm conditions, methanogens (methane producing bacteria) and other bacteria contribute to the degradation of the biomass, producing a gas high in methane (CH_4) and carbon dioxide (CO_2) that, when burned, generates energy. For each m^3 of biogas, approximately 6 kWh of energy is produced [figure 3] (Vögeli 2014).

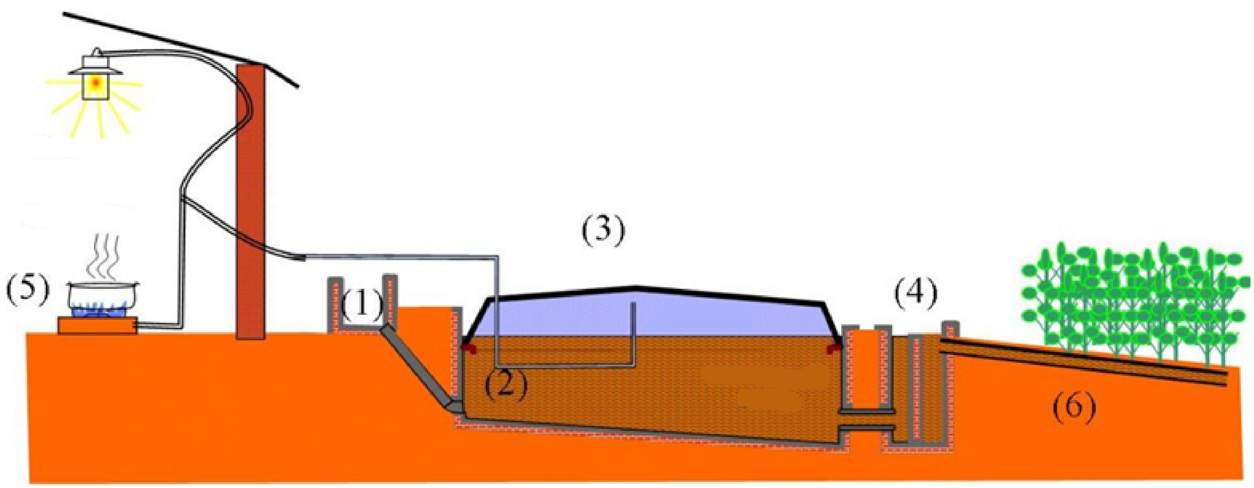


Figure 3: Production of biogas using a biodigester
Biomass substrate enters the biodigester in a liquid, homogeneous form at (1). It is retained in the biodigester, while it biodegrades, producing biogas (3) and a fertile digestate (4).
Source: Association n.d.

In addition to providing energy for the still and preserving forest resources, biogas produced from pig and zebu manure could benefit the community of Faliarivo by improving local sanitation, especially by reducing contamination of the river. Furthermore, the process of decomposition of organic materials also produces digestate, a sanitary and potent fertilizer which could be used by local farmers to improve crop yields (Kossmann Vol. 1 n.d.). Additionally, the introduction of biogas technology to Faliarivo could precipitate the development of local, household biogas projects. The benefits to household biogas use are threefold. First, it could further decrease pressure on forest resources by reducing household demand for wood, one of the primary sources of forest degradation. Second, it could decrease household expenses. Third, it could decrease household exposure to smoke, which is toxic to the eyes and lungs and accounts for 11,000 deaths each year in Madagascar (Association n.d.). While household biogas use was outside of the scope of this research, the principles and best practices of biogas implementation are transferrable to future projects.

While the potential benefits of a successfully implemented biogas project in Faliarivo are significant, the feasibility of such a project must first be evaluated. This study attempted to determine the feasibility of installing a biogas project. In particular, the research addressed the following questions:

i. What are the forms of feedstock available to Faliarivo?
ii. What is the quantity of feedstock available?
iii. Would the resulting biogas provide sufficient energy to meet the desired operating schedules of the still?
iv. What is the social feasibility of using biogas?

By considering the answers to these questions, this study attempted to, first, determine the viability of a biogas installation, and second, to establish a series of transferrable best practices for the implementation of a biogas project in Faliarivo.

II. Methods

In order for a biogas to be a viable alternative source of energy for the still, the quantity of energy produced must be able to meet all or most of the quantity of energy needed to perform the desired number of distillations. Therefore, this study evaluated both fuel demand and feedstock availability.

Fuel Demand

Due to an ongoing government-mandated environmental risk assessment (ONE), the still in Faliarivo is currently non-operational. As a result, fuel demand was determined through anecdotal data provided in key stake holder interviews with the still's technician and a Ny Tanintsika field agent. The interviews discussed the quantity of wood, Ravintsara, and time needed to perform a single distillation. The quantity of wood was provided in m^3 and the quantity of Ravintsara in kg. Furthermore, interviews inquired about potential operating schedules of the still on a daily, weekly, and monthly basis. Interviews were performed on a voluntary basis at the convenience of the interviewee, and reflected their personal experiences with the still. Interviews with the technician and distiller were administered in French and translated into Malagasy with the aid of a translator. Interviews with the Ny Tanintsika field agent were conducted in French.

In addition to key stake holder interviews, a single sample distillation was observed in the village of Tolongoina, the other site of the Ny Tanintsika essential oils project. During the sample distillation, the volume and mass of a typical piece of firewood was measured to determine the conversion factor from volume (m^3) to mass. At three separate times during the distillation, separated by 30 minute intervals, four pieces of firewood were randomly selected, measured, and weighed. The pieces of firewood were chosen by selecting the fifth, tenth, fifteenth, and twentieth counted piece within the stacked wood. Counting preceded from bottom to top, and from left to right, as possible, within the stack. For each piece of wood, the length was measured using a 5 m tape measure. Width was measured at five regular intervals along two different sides of the plank. The regular integral was equal to one fourth of the total length, so that both ends of the log were measured, as well as three other evenly spaced points along the log [figure 4]. Each piece was also weighed using a 10 kg spring scale.

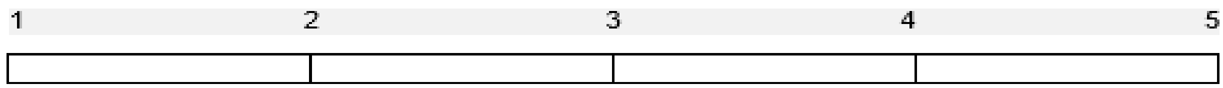


Figure 4: Location of width measurements on a log of firewood

The collected data was used to estimate the volume of each plank by approximating the plank as a series of four pyramidal frustums, each of which was de fined by the two adjacent cross sections. The volume of each segment was calculated separately, and the total found. The formula is as follows, where l is the total length of the plank, w and h are the dimensions of the first cross section, and W and H are the dimensions of the second cross section:

$$V = \sum_{all\ segments} \frac{1}{3}\frac{l}{4}(w\,h + \sqrt{whWH} + WH)$$

The volume of each plank, together with its mass, was used to calculate the average density of firewood according to the following formula, where m is mass, v is volume, and n is the sample size:

$$average\ density = \frac{\sum_{all\ planks}\frac{m}{V}}{n}$$

By multiplying the average density of the wood by the volume of firewood needed per distillation, the total mass of wood consumed was found. The needed volume of firewood was reported in key stake holder interviews conducted in Faliarivo. Since wood is purchased by stacked cubic meters, the total volume has both filled and void areas. As a result, the total volume of firewood purchased was multiplied by the estimated proportion of filled space, a figure determined by secondary literature. The formula is as follows, where ρ is the average density of firewood, f is the fraction of filled space, and V is the volume of stacked wood:

$$wood\ mass\ per\ distillation = \rho f V_{stacked\ wood}$$

In turn, assuming that burning virgin deciduous wood produces between 18.5 and 19.2 MJ/kg of useful energy (the net calorific value, or NCV), the mass of wood can be used to determine the total energy released during a distillation (Francescato 2008). While this figure does not take into account boiler efficiency, a biogas burner would be similarly effected by boiler efficiency, so it is only the total emitted energy which is considered here. Finally, by multiplying the distillation energy by the total number of desired distillations, the total energy needed on an annual basis can be found. The formula is below, where N is the total number of distillations, C is the NCV, and m is the mass of wood burned per distillation:

$$Total\ emitted\ energy = NCm_{distillation}$$

Feedstock Availability

The total emitted energy estimates the demand for energy by the still. To determine if biogas could meet this demand, the quantity and potential output of the available feedstock sources must be evaluated. This study conducted a general survey of available organic material in Faliarivo to determine the range of feedstock sources available. The survey was conducted through general observation and key stakeholder interviews with the still's technician, his wife, and the distiller. Each interview inquired about three categories of organic materials: animal byproducts, household waste, and agricultural materials. Plant matter was further divided into three categories: weeds, invasive species, and post-harvest rice plants. Interview subjects were asked about the specific forms of each material available in Faliarivo and their current treatment, including disposal and use, if any. Finally, interview subjects were asked if there were any additional forms of organic material available in Faliarivo. Each interview was conducted separately. Interviews were performed on a voluntary basis at the convenience of the interviewee, and reflected their personal experiences. Interviews were administered in French and translated into Malagasy with the aid of a translator.

The final list of organic materials was coded into the three categories, animal byproducts (B), household waste (W), and agricultural materials (A). While this analysis did not provide information on the relative abundance of the specific feedstock sources, it did provide an approximate description of the composition of organic materials available in Faliarivo.

From this list, four organic materials were chosen for further study. The materials were chosen according to four criteria, listed here in order of decreasing importance: current use, biogas potential, accessibility, and abundance. Current use refers to the utilization of waste materials for secondary uses. Since this study, as one of its purposes, works to contribute to the preservation of resources for the local community, any materials which had a consistent secondary use within Faliarivo were not evaluated for their biogas potential.

The second criterion, biogas potential, refers both to a material's potential biogas output and its effect on the digestion environment. So, a material which would benefit the digestion process and environment or which resulted in a large output of high methane-content biogas was considered for further study, regardless of its abundance.

Accessibility, the third criterion, recognizes that the geography of the valley prohibits the use of some organic materials. To collect material outside of the village, an individual could have to walk an hour or more along steep hillsides and through deep or fast-flowing rivers. Materials which were prohibitively far or which had only marginal biogas potential compared to the required collection effort were eliminated from consideration. However, materials which could be modified to increase accessibility remained under consideration.

The final criterion, abundance, acknowledged that more abundant materials have larger and sustained output potential. However, in the event of the implementation of a biogas plant in Faliarivo, organic material sources could be created or modified to maximize the available quantity, mitigating the importance of this criterion.

For each of the four selected organic materials, both the available biomass and the social feasibility of its use was evaluated.

Kitchen Waste

Available Biomass

To determine the mass of organic kitchen waste theoretically available for the production of biogas, the average daily mass of waste per household and per capita was found. Randomly selected households participating in the household structured survey, which collected demographic data and evaluated attitudes toward three sources of biomass (kitchen waste, zebu manure, and pig manure), were asked at the end of the interview if they were interested in collecting their kitchen waste over the course of one day [appendix A]. Survey participants were randomly selected. Within each of five regions within the village center of Faliarivo, participants were selected by asking the guide and translator, alternatively, to choose a random number between 1 and 10. Once a number was chosen, the houses were counted, starting at 1, left to right, preceding in approximately parallel rows down the length of the region. Upon reaching the chosen random number, the household assigned that value was, if present, asked to participate within the structured survey. If no one was present, the next household with an inhabitant was selected. If an inhabited household declined, a new random number was chosen, and counting the next house in the region as 1, the process was repeated. All structured survey participants were asked to participate in the kitchen waste collection survey unless they had participant had previously agreed to provide additional information on the availability of pig manure. Interviews were administered in French and translated into Malagasy with the aid of a translator. Survey participants were given one cup of rice following the completion of the interview. Those who collected their kitchen waste were given an additional cup after the waste was weighed.

If a subject agreed to participate, the collected waste was weighed at 6 p.m. the following day in whatever container was provided. After the waste was disposed of, the weight of the container was found. All weights were measured with a 10 kg spring scale. The number of individuals living within the household, as reported by the subject with the aid of a translator, and the region where the household was located were also recorded. The resulting data provided information on the average daily mass of kitchen waste produced per household and per capita.

The average daily mass of kitchen waste was in turn used to calculate the total mass of kitchen waste. Two methods were used. In the first, the average daily mass of kitchen waste per capita was multiplied by the estimated population of the village center of Faliarivo, defined as the area within the five established regions. The population was estimated by calculating the average number of inhabitants per household in each region and multiplying by the number of houses in each region. The average number of inhabitants per household was found from the inhabitancy levels reported by structured survey participants. The number of houses in each region was counted manually, and excluded any buildings which were evidently uninhabited, unfinished, or external kitchens or bathrooms. Hence, the population was found according to the following formula, where n is the number of households in a region and r is the average inhabitancy level of the region:

$$population = \sum_{all\ regions} n_{region} r_{region,avg}$$

In turn, the total mass of kitchen waste can be found as follows, where P is the population and m is the average daily mass of kitchen waste per capita:

$$total\ daily\ mass\ of\ kitchen\ waste = Pm_{avg\ per\ capita}$$

Social Feasibility

To determine the social feasibility of using kitchen waste to produce biogas, a structured survey was administered to randomly and non-randomly selected participants [appendix A, C4]. Interviews were administered in French and translated into Malagasy with the aid of a translator. Survey participants were given one cup of rice following the completion of the interview. The survey, included in Appendix 1, included questions on the household's current production and treatment of kitchen waste, as well as their willingness to contribute their waste to a biogas project. Questions asked specifically about various waste collection procedures to evaluate which approaches would likely result in the highest participation rates. To determine the most popular waste collection procedures, responses were analyzed according to the proportion of particular answer.

Zebu Dung

Available Biomass

In Faliarivo, most zebu wander the surrounding countryside during the day, making the collection of free zebu droppings time consuming and challenging. However, each night a portion of the zebu return to a fenced enclosure near the village to sleep. The enclosure is owned by the Ampanjaka of Faliarivo, who granted permission to enter and use the field for the duration of the study. In order to determine the quantity of available biogas, the quantity of fresh dung available on a daily basis within the enclosure was found. The study limited itself to fresh dung for two reasons. First, after utilizing all older feces in the initial moments of the biogas plant, only the dung produced on a daily basis would sustain plant operation. Second, fresh dung has decomposed less than older dung, and as a result has the potential to produce more biogas within the digester environment (Kossmann Vol. 2 n.d.).

The quantity of fresh dung available on a daily basis was based on the average number of fresh droppings produced each night and the average mass of a fresh dropping. The number of fresh droppings was counted on each of three mornings, within fifteen minutes of the last zebu leaving the enclosure. Only those droppings which were left the previous night and equal to or larger than 10 cm of diameter were counted. Smaller droppings were neglected due to their negligible contribution to the available biomass and because they were frequently part of a larger defecation. The freshness of a dropping was determined with the aid of the enclosure's guard, a Ny Tanintsika field agent, and a translator.

To determine the average mass of fresh zebu feces, five droppings were randomly selected on each of four days. The enclosure was divided into six regions, each of which had a maximum radius smaller than or equal to approximately 20 paces. Five numbers between one and six were chosen at random to determine the region where each dropping would be selected. To choose a dropping within a region, a four-by-four grid was created with axes labeled with randomly chosen numbers from one to eight. Random numbers between one and twenty were placed at random throughout the grid. Then, random numbers between one and eight were selected until two were chosen which were on different axes, forming a coordinate pair. The number at the selected coordinate indicated the number of paces to take from the center of the selected region, and the orientation of the coordinate from the center of the grid indicated the direction in which to walk. From the resulting location, the nearest fresh dropping with a diameter of greater than 10 cm was collected in a plastic bag and weighed using a 10 kg spring scale. All random numbers were supplied by the Ny Tanintsika field agent and translator, who provided numbers on an alternating basis.

The average number of fresh zebu droppings per day was multiplied by the average mass of a fresh zebu dropping to estimate the total available biomass. Thus, the available biomass is as follows, where n is the average number of droppings per day and m is the average mass:

$$total\ daily\ mass\ of\ zebu\ dung = n_{avg}m_{avg}$$

The results from both methods were compared and evaluated.

Social Feasibility

To determine the social feasibility of using zebu excrement to produce biogas, a structured survey was administered to randomly and non-randomly selected participants who indicated that they owned one or more zebu [appendix A, C7]. Interviews were administered in French and translated into Malagasy with the aid of a translator. Survey participants were given one cup of rice following the completion of the interview. The survey, included in appendix A, asked owners about the number of zebus they had, their current location, and their willingness to contribute their waste to a biogas project. Questions asked specifically about various waste collection procedures to evaluate which approaches would likely result in the highest participation rates. To determine the most popular waste collection procedures, responses were analyzed according to the proportion of particular answer.

Pig Dung

Available Biomass

The quantity of pig dung available for biogas production was determined on the basis of the number of pigs in Faliarivo and the average daily fecal mass produced. The number of livestock was determined by extrapolating the proportion of structured survey participants who reported owning pigs and the average number of pigs owned to the population of the center village of Faliarivo. The formula is as follows, where p is the population, $n_{avg\ pigs}$ is the average number of pigs per pig owner, $n_{pig\ owners}$ is the total number of reported pig owners participating in structured survey, and N is the sample size:

$$total\ pig\ population = Pn_{avg\ pigs}\frac{n_{pig\ owners}}{N}$$

The total estimated pig population was in turn multiplied by the average nightly mass of excrement produced per pig, a quantity found by weighing the droppings of the pigs owned by consenting survey participants. The number and size of the pigs was recorded, along with the number of distinct droppings and the period of time during which the droppings were produced. The droppings were placed in a plastic bag and weighed using a 10 kg spring scale. The number of droppings was averaged over time and the total number of pigs to find the average nightly mass of dung per pig. Then, the total nightly mass of pig dung was found as follows, where p is the estimated pig population and m is the average nightly mass of dung per pig:

$$total\ nightly\ mass\ of\ pig\ dung = pm_{avg}$$

Social Feasibility

To determine the social feasibility of using zebu excrement to produce biogas, a structured survey was administered to randomly and non-randomly selected participants who indicated that they owned one or more pig [appendix A]. Interviews were administered in French and translated into Malagasy with the aid of a translator. Survey participants were given one cup of rice following the completion of the interview. The survey, included in appendix A, asked owners about the number of pigs they had, their current location, and their willingness to contribute their waste to a biogas project. Questions asked specifically about various waste collection procedures to evaluate which approaches would likely result in the highest participation rates. To determine the most popular waste collection procedures, responses were analyzed according to the proportion of particular answer.

Biogas Availability

For each potential feedstock source, the daily quantity of available biomass was converted to the quantity of biogas that would be produced each day using the specific gas yield of each substrate, a figure provided by secondary literature which assumes that digestion occurs in warm tropical countries. Then, using the energy content of biogas, a literature provided value which is specific to the biomass type, the energy output of the resulting biogas was determined. Once again, because the still boiler is invariable, the efficiency of the boiler was not considered in calculating total energy output.

The resulting energy output was compared to the total energy output resulting from burning firewood to determine the proportion of the still's energy demand which biogas could fulfill. If the minimum potential energy output of biogas was equal to or greater than the maximum current energy output, it is assumed that biogas could completely fulfill all energy needs of the still. If the minimum potential energy output of biogas was less than the still's maximum energy demand, further evaluation will be recommended.

III. Results

Fuel Demand

To determine the daily and yearly fuel demand, it was necessary to find the number of planned distillations per day and per year, the volume of wood needed per distillation, the average density of wood, and the NCV. The distiller reported that no operating schedule for the still had been established since it was still undergoing governmental evaluation. However, he also stated that a privately-owned still in a nearby village performed four distillations of

Ravintsara essential oils per day during the course of one month. Given the capacity of the Faliarivo COBA, the distiller estimated that they could maintain this operating schedule for the entirety of the Ravintsara season, a period which stretches from the beginning of April to the end of September. Assuming that distillations occur four times per day, five times per week for the course of six months, approximately 525 distillations would be completed each year. In order to account for error, all calculations were repeated assuming that 500, 525, and 550 distillations could be completed per year.

The wood consumed by a single distillation was reported by both the still's technician and the Ny Tanintsika field agent to be between 0.35 and 0.5 m^3 of Eucalyptus, mango, or litchi wood, depending on the quality of the wood (appendix B3). If the wood is well dried, a distillation can be completed with 0.35 m^3 of wood, but if the wood is still wet, more wood is required. The average density of wood was experimentally determined to be 506.2 kg/m^3 (appendix B1, B2). Literature reported that the range of NCVs for virgin deciduous wood materials was between 18.5 and 19.2 MJ/kg (Francescato 2008).

Table 4 shows the daily energy produced by the still during the six months of operation. The total energy ranged from approximately 10,500 MJ/day to 15,500 MJ/day, depending on the volume of wood consumed and the NCV of the wood.

Tables 1, 2, and 3, included below, show the total energy produced in MJ/year according to the volume of wood per distillation, distillations per year, and net calorific value. The total energy produced ranged from approximately 1.3 million MJ/year (500 distillations per year, 0.35 m^3 of wood per distillation, and an NCV of 18.5) to 2.1 million MJ/year (550 distillations per year, 0.5 m^3 of wood per distillation, and an NCV of 19.2).

Table 1: Total Yearly Energy Produced for Wood with NCV of 18.5 MJ/kg

Net Calorific Value = 18.5 MJ/kg

Distillations per Year = 500

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	500	70,868	18.5	1,311,058
0.4	0.8	506.2	162.0	500	80,992	18.5	1,498,352
0.45	0.8	506.2	182.2	500	91,116	18.5	1,685,646
0.5	0.8	506.2	202.5	500	101,240	18.5	1,872,940

Distillations per Year = 525

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	525	74,411	18.5	1,376,611
0.4	0.8	506.2	162.0	525	85,041	18.5	1,573,270
0.45	0.8	506.2	182.2	525	95,671	18.5	1,769,928
0.5	0.8	506.2	202.5	525	106,302	18.5	1,966,587

Distillations per Year = 550

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	550	77,954	18.5	1,442,164
0.4	0.8	506.2	162.0	550	89,091	18.5	1,648,187
0.45	0.8	506.2	182.2	550	100,227	18.5	1,854,211
0.5	0.8	506.2	202.5	550	111,364	18.5	2060234

Table 2: Total Yearly Energy Produced for Wood with NCV of 18.85 MJ/kg

Net Calorific Value = 18.85 MJ/kg

Distillations per Year = 500

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	500	70,868	18.85	1,335,862
0.4	0.8	506.2	162.0	500	80,992	18.85	1,526,699
0.45	0.8	506.2	182.2	500	91,116	18.85	1,717,537
0.5	0.8	506.2	202.5	500	101,240	18.85	1,908,374

Distillations per Year = 525

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	525	74,411	18.85	1,402,655
0.4	0.8	506.2	162.0	525	85,041	18.85	1,603,034
0.45	0.8	506.2	182.2	525	95,671	18.85	1,803,413
0.5	0.8	506.2	202.5	525	106,302	18.85	2,003,793

Distillations per Year = 550

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	550	77,954	18.85	1,469,448
0.4	0.8	506.2	162.0	550	89,091	18.85	1,679,369
0.45	0.8	506.2	182.2	550	100,227	18.85	1,889,290
0.5	0.8	506.2	202.5	550	111,364	18.85	2,099,211

Table 3: Total Yearly Energy Produced for Wood with NCV of 19.2 MJ/kg

Net Calorific Value = 19.2 MJ/kg

Distillations per Year = 500

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	500	70,868	19.2	1,360,666
0.4	0.8	506.2	162.0	500	80,992	19.2	1,555,046
0.45	0.8	506.2	182.2	500	91,116	19.2	1,749,427
0.5	0.8	506.2	202.5	500	101,240	19.2	1,943,808

Distillations per Year = 525

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	525	74,411	19.2	1,428,698
0.4	0.8	506.2	162.0	525	85,041	19.2	1,632,798
0.45	0.8	506.2	182.2	525	95,671	19.2	1,836,898
0.5	0.8	506.2	202.5	525	106,302	19.2	2,040,998

Distillations per Year = 550

Volume of Wood (m^3)	Proportion of Filled Space	Average Density (kg/m^3)	Wood per Distillation (kg/distillation)	Distillations per Year	Total Wood Consumed (kg/year)	NCV (MJ/kg)	Total Energy Produced (MJ/year)
0.35	0.8	506.2	141.7	550	77,954	19.2	1,496,732
0.4	0.8	506.2	162.0	550	89,091	19.2	1,710,551
0.45	0.8	506.2	182.2	550	100,227	19.2	1,924,370
0.5	0.8	506.2	202.5	550	111,364	19.2	2,138,189

Table 4: Total Daily Energy Produced by Wood

Volume of Wood (m³)	Proportion of Filled Space	Average Density (kg/m³)	Wood per Distillation (kg/distillation)	Distillations per Day	Total Wood Consumed (kg/day)	NCV (MJ/kg)	Total Energy Produced (MJ/day)
0.35	0.8	506.2	141.7	4	566.944	18.5	10,488
0.4	0.8	506.2	162.0	4	647.936	18.5	11,987
0.45	0.8	506.2	182.2	4	728.928	18.5	13,485
0.5	0.8	506.2	202.5	4	809.92	18.5	14,984
0.35	0.8	506.2	141.7	4	566.944	18.85	10,687
0.4	0.8	506.2	162.0	4	647.936	18.85	12,214
0.45	0.8	506.2	182.2	4	728.928	18.85	13,740
0.5	0.8	506.2	202.5	4	809.92	18.85	15,267
0.35	0.8	506.2	141.7	4	566.944	19.2	10,885
0.4	0.8	506.2	162.0	4	647.936	19.2	12,440
0.45	0.8	506.2	182.2	4	728.928	19.2	13,995
0.5	0.8	506.2	202.5	4	809.92	19.2	15,550

Feedstock Availability

The predominant source of organic material in Faliarivo came from agricultural sources, with 70% of potential biomass sources originating in agriculture. In addition to three types of invasive species, Vakoka, Harongana, and Albeza, the distiller suggested that the Ravintsara leaves that remain at the end of a distillation be used for biogas creation. In addition, during walking observations of Faliarivo and the surrounding areas, many discarded weeds were observed outside of rice paddies. Additionally, previously harvested rice fields were often filled with the remnants of rice plants. Lastly, because of the presence of many *toaka gasy* distilleries outside of the village center, it is possible that the discarded sugarcane waste could be used as a source of biogas. While none of these sources had a secondary use, and while all were relatively abundant, they were all relatively inaccessible compared to biomass sources located in and immediately outside of the village. Moreover, the production of biogas requires the presence of methanogens in the biodigester. These bacteria are not naturally present in green matter, and so an additional, consistent source of bacteria would have to be introduced to the substrate. Moreover, because the green matter is frequently fresh, it takes longer to decompose, and requires more diligent plant supervision (Kossmann Vol. 2 n.d.).

After agricultural sources, the next most significant source of organic material in Faliarivo originated from animals. All interview subjects reported that zebus and pigs were the only large or medium sized animals raised in Faliarivo. Zebu were reported to spend most of their time in the surrounding countryside. However, a group of zebu were reported to spend nights in a public enclosure located immediately outside of the village, on the bank of the river. The public enclosure was owned by the *ampanjaka*, or king, of the village. In contrast, while every interview subject stated that there were many pigs in Faliarivo, they identified no specific place where the pigs were consolidated. Furthermore, upon further discussion, multiple interview subjects, including the wife of the still's technician, stated that a recent pig pestilence killed most of the pigs in Faliarivo. However, despite the lack of abundance of pig manure, the potential benefits to the digestion environment are significant enough that it was included in the study. Both pig and zebu manure naturally contain methanogens, facilitating plant maintenance. (Kossmann Vol. 2 n.d.).

The last observed source of organic material was kitchen waste. Kitchen waste was abundant and easily accessed. The wife of the still's technician stated that there was a public dump located in the middle of the village, on the bank of the river, where many individuals disposed of their organic kitchen waste. Moreover, while kitchen waste does not naturally contain methanogens, it takes less time to decompose than green matter, facilitating its degradation and the release of biogas (Vögeli 2014).

Kitchen Waste

Available Biomass

The daily mass of kitchen waste was measured for 22 participants, resulting in an average daily mass per capita of 1.09 kg (appendix C2). Together with the estimated population of Faliarivo of 1,540, this produced a total daily mass of kitchen waste of approximately 1,600 kg and a total yearly mass of kitchen waste of approximately 600,000 kg (appendix C3).

Table 5: Daily and Yearly Mass of Kitchen Waste

Population	Average Daily Mass of Kitchen Waste per Capita (kg/day·person)	Total Daily Mass of Kitchen Waste (kg/day)	Total Yearly Mass of Kitchen Waste (kg/year)
1540	1.09	1,678.72	612,731

Social Feasibility

Social feasibility was evaluated using a structured survey, included in Appendix A. 28 individuals consented to participating in the structured survey. Of the respondents, 61% were women and 39% were men. 63% of participating women reported that they were responsible for some or all of the cooking in the household (Figure 5). Of the men, 69% responded that their wives were responsible for some or all of the cooking in the household (Figure 6). Together, in approximately 66% of participating households, the wife cooks the meals. This accounts for the majority of the individuals responsible for cooking.

Figure 5: Individuals Responsible for Cooking, Female Respondents

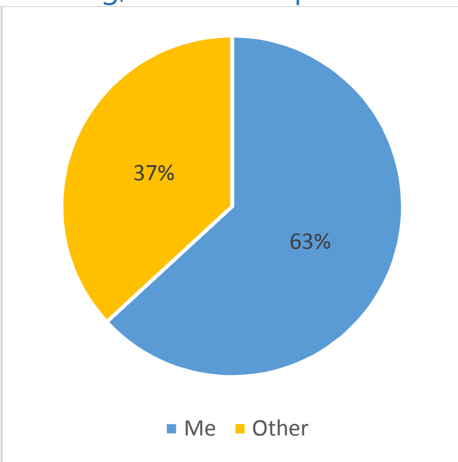
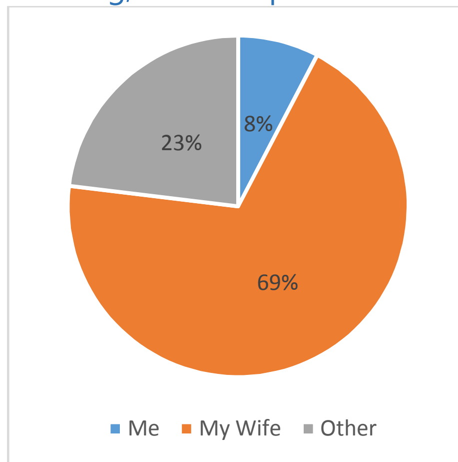
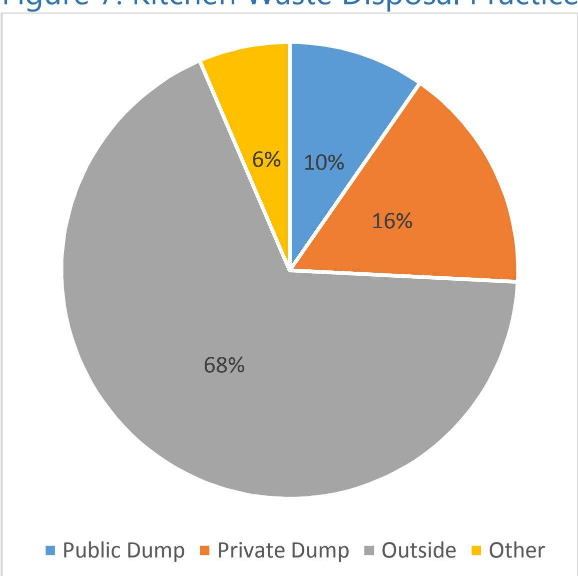


Figure 6: Individuals Responsible for Cooking, Male Respondents



Of those who cooked, the majority (21 individuals, constituting 68% of responses) were reported to dispose of their kitchen waste outside of their homes. Three individuals, constituting 10% of responses, stated that they used a public dump located in Faliarivo, while five individuals (13% of responses) reported using a private dump near their homes (figure 7). Two individuals reported disposing of their kitchen waste in two or more locations.

Figure 7: Kitchen Waste Disposal Practices by Household



Of the 25 individuals who did not use the public dump for any portion of their kitchen waste, 24 (96%) stated that they would be willing to use a public dump to contribute their waste to a biogas project. The individual who was unwilling to use the public dump stated that she lived too far from the village to use a village dump. However, she stipulated that if she were paid to use the public dump, she would do so. She further stated that she would grant permission to the employees of the still to collect her kitchen waste from her home.

Of the three individuals who did use the public dump, two (67%) stated that they would be willing to authorize the employees of the still to collect the dump's waste for a biogas project. The individual who was unwilling to grant permission stated that he was concerned with the structural integrity of the current dump. He further said that he would be willing to use a public dump for the purpose of biogas creation if a new, structurally sound dump was constructed.

The 27 individuals who stated that they would be willing to use a new or old public dump were asked if they would be willing to move the public dump closer to the still to facilitate the production of biogas. 81% responded affirmatively. The remaining 19% all stated that the still was too far from their houses. These individuals lived in regions 1 (one individual), 2 (two individuals), and 3 (two individuals). One of these individuals stated that he would be willing to use a public dump near the still if he was paid to do so. Lastly, two individuals surveyed expressed that their permission to move the public dump was conditional on the agreement of the rest of the inhabitants of the village.

Zebu Dung

Available Biomass

The quantity of available zebu dung was also estimated by finding the average number and weight of fresh zebu droppings. The number of fresh zebu droppings varied between 37 and 92, with an average of 69 fresh droppings. To recognize this variation, the total nightly quantity of zebu dung was determined for each of three values of fresh droppings per night. The average weight of fresh zebu dung was determined to be 1.2 kg. As a result, the total nightly mass of zebu dung could range between 36 and 108 kg/night, with a median of 72 kg/night (table 6).

Table 6: Nightly and Yearly Mass of Zebu Dung

Number of Fresh Zebu Droppings per Night	Average Mass of Fresh Zebu Droppings (kg)	Total Nightly Mass of Zebu Droppings (kg)	Total Yearly Mass of Zebu Droppings (kg)
30	1.2	36	13,140
50	1.2	60	21,900
70	1.2	84	30,660
90	1.2	108	39,420

Social Feasibility

Social feasibility was evaluated using a structured survey, included in appendix A. 28 individuals consented to participating in the structured survey. Of those, 12 (43%) stated that their household owned one or more zebu. The average number of zebu reported was 6, with a minimum of 2 and a maximum of 14. Of those with zebu, only 2 (17%) stated that they used the public enclosure. Of the 10 whose zebu did not use the public enclosure, nine were asked if they would be willing to use a public enclosure to facilitate the production of biogas. Two (22%) were willing to use a public enclosure. The remaining seven stated that they were unwilling to use a public enclosure for various reasons, including distance and security.

Of the four individuals who used or who were willing to use the public enclosure, three (75%) stated that they would be willing to move the public enclosure closer to the still to facilitate the collection of manure. The fourth individual stated that he would be willing to move the public enclosure closer to the still on the condition that an enclosure with a modern fence was constructed. In addition, out of seven responding individuals, including four who were unwilling to use a public enclosure, 100% stated that they would be willing to authorize the employees of the still to collect zebu manure for the production of biogas.

Of the nine participating individuals who reported that their zebu lived near Faliarivo, three (33%) stated that they used zebu manure as fertilizer. Each of those three respondents also stated that the manure was used for the community vegetable garden, and that it was only used occasionally.

Pig Dung

Available Biomass

Of the 21 households randomly selected for the structured survey, three reported that they owned pigs. Assuming that this proportion of pig owners is consistent across the household, and given that the study counted 249 households in Faliarivo, there are approximately 36 pig owners in Faliarivo. Eight households surveyed reported owning between one and four pigs, with an average of two pigs per household. Thus, it is estimated that there are 72 pigs in Faliarivo.

Three households who owned pigs consented to participate in a survey of the weight of pig dung. The results, presented below in table 6 , estimate that each night, one pig produces 0.16 kg of dung. Then, ssuming that there are 72 pigs in Faliarivo, the total nightly mass of pig dung in Faliarivo is approximately 11.52 kg. The total yearly mass of pig dung is 4,205 kg (table 7).

Table 6: Nightly Mass of Dung per Pig

Household	Number of Pigs	Size of Pigs	Time Period (Hours)	Total Weight of Dung (kg)	Mass of Dung per Pig (kg)	Nightly Mass of Dung per Pig (kg)
1	2	2M	12	0.2	0.1	0.1
2	4	3M, 1S	24	1.15	0.2875	0.14
3	1	1L	12	0.25	0.25	0.25
Average	**2**				**0.21**	**0.16**

Table 7: Total Yearly Mass of Pig Dung

Number of Pigs	Nightly Mass of Dung per Pig (kg)	Total Nightly Mass of Pig Dung (kg)	Total Yearly Mass of Pig Dung (kg)
72	0.16	11.52	4,205

Social Feasibility

Social feasibility was evaluated using a structured survey, included in Appendix A. 28 individuals consented to participating in the structured survey. Eight households with pigs were surveyed. None of the households reported using pig manure for fertilizer or other purposes.

Five of those households (63%) stated that the pigs spent nights in the village. Of those, four (80%) stated that they would be willing to authorize the employees of the still to collect their pig manure to produce biogas. The fifth individual reported that she did not have a pig pen, allowing the pigs to wander freely on her property. As a result, she stated that it would be difficult for the employees to find and collect the pigs' manure.

Biogas Availability

If utilized for biogas production, kitchen waste could produce between 579 and 6,512 MJ/day of energy [table 10]. On a yearly basis, it could produce between 211,230 and 2.4 million MJ [table 11].

If utilized for biogas production, zebu dung could produce between 31 and 93 MJ/da4y of energy [table 12]. On a yearly basis, it could produce between 11,353 and 34,059 MJ [table 13].

If utilized for biogas production, pig dung could produce 9.95 MJ/day of energy [table 14]. On a yearly basis, it could produce 3,633 MJ [table 15].

Based on the minimum and maximum energy production levels for each of the feedstock sources, and assuming that there are no interactions between organic materials that alter biogas production, the minimum amount of energy produced from biogas would be 620 MJ/day or 226,216 MJ/year [table 8]. The maximum quantity of energy produced would be 6,615 MJ/day or 2,414,034 MJ/year [table 9].

Table 8: Total Minimum Energy Production, Daily and Yearly

Source	Energy Content (MJ/day)	Energy Content (MJ/year)
Kitchen Waste	579	211,230
Zebu Dung	31	11,353
Pig Dung	10	3,633
Total	**620**	**226,216**

Table 9: Total Maximum Energy Production, Daily and Yearly

Source	Energy Content (MJ/day)	Energy Content (MJ/year)
Kitchen Waste	6,512	2,376,342
Zebu Dung	93	34,059
Pig Dung	10	3,633
Total	**6,615**	**2,414,034**

Table 10: Daily Energy Production from Kitchen Waste

Daily Mass of Kitchen Waste (kg/day)	Fraction of TS (Percent of Raw Waste)	TS (kg/day)	Fraction of VS (Percent of TS)	VS (kg/day)	Methane Yield (L/kg VS)	Methane Yield (L)	Methane Yield (m^3)	Energy Content (kWh/m^3)	Energy Content (kWh/day)	Energy Content (MJ/day)
1,679	5%	84	76%	63.8	420	26,797	26.80	6	160.78	578.81
1,679	5%	84	95%	79.8	420	33,496	33.50	6	200.98	723.51
1,679	45%	756	76%	574.2	420	241,172	241.17	6	1,447.03	5,209.31
1,679	45%	756	95%	717.8	420	301,464	301.46	6	1,808.79	6,511.63

Table 11: Yearly Energy Production from Kitchen Waste

Yearly Mass of Kitchen Waste (kg/year)	Fraction of TS (Percent of Raw Waste)	TS (kg/year)	Fraction of VS (Percent of TS)	VS (kg/year)	Methane Yield (L/kg VS)	Methane Yield (L)	Methane Yield (m^3)	Energy Content (kWh/m^3)	Energy Content (kWh/year)	Energy Content (MJ/year)
612,731	5%	30,637	76%	23283.8	420	9,779,187	9,779.19	6	58,675.12	211,230
612,731	5%	30,637	95%	29104.7	420	12,223,983	12,223.98	6	73,343.90	264,038
612,731	45%	275,729	76%	209554.0	420	88,012,681	88,012.68	6	528,076.09	1,901,074
612,731	45%	275,729	95%	261942.5	420	110,015,851	10,015.85	6	660,095.11	2,376,342

Table 12: Daily Energy Production from Zebu Dung

Nightly Mass of Zebu Droppings (kg/day)	Biogas Content (L/kg)	Biogas Yield (L/day)	Biogas Yield (m^3/day)	Energy Content (kWh/m^3)	Energy Content (kWh/day)	Energy Content (MJ/day)
36	40	1440	1.44	6	8.64	31.10
60	40	2400	2.4	6	14.4	51.84
84	40	3360	3.36	6	20.16	72.58
108	40	4320	4.32	6	25.92	93.31

Table 13: Yearly Energy Production from Zebu Dung

Yearly Mass of Zebu Droppings (kg/year)	Biogas Content (L/kg)	Biogas Yield (L/day)	Biogas Yield (m^3/year)	Energy Content (kWh/m^3)	Energy Content (kWh/year)	Energy Content (MJ/year)
13,140	40	525600	525.6	6	3,153.60	11,353
21,900	40	876000	876	6	5,256.00	18,922

	30,660	40	1226400	1226.4	6	7,358.40	26,490
	39,420	40	1576800	1576.8	6	9,460.80	34,059

Table 10: Daily Energy Production from Pig Dung

Nightly Mass of Pig Droppings (kg/day)	Biogas Content (L/kg)	Biogas Yield (L/day)	Biogas Yield (m^3/day)	Energy Content (kWh/m³)	Energy Content (kWh/day)	Energy Content (MJ/day)
11.52	40	460.8	0.4608	6	2.76	9.95

Table 11: Yearly Energy Production from Pig Dung

Yearly Mass of Pig Droppings (kg/year)	Biogas Content (L/kg)	Biogas Yield (L/day)	Biogas Yield (m^3/year)	Energy Content (kWh/m³)	Energy Content (kWh/year)	Energy Content (MJ/year)
4,205	40	168200	168.2	6	1,009.20	3,633

IV. Discussion

Fuel Demand

The calculated fuel demand estimated the range of the energy demand of the still. The daily energy demand was calculated to fall between 10,000 MJ and over 15,000 MJ, spanning a range of over 5,000 MJ. The yearly energy demand spanned a range of 0.8 million MJ. The lack of conclusive results is attributable to several things. First, the essential oils project is still in test phases. As a result, the operating schedule is undetermined, resulting in a wide range of possible operating frequencies. Second, due to normal variations in wood dryness, the volume of wood varies between distillations. These variations were inevitable given the timing and timeframe of the study.

Moreover, the measured density used in calculations was not specific to the wood used at the still in Faliarivo. Because the distillation observed in Tolongoina was a test run, wood was collected from invasive species from the surrounding countryside rather than from a plantation. Since the density of a wood is specific to its species, the measured density did not accurately reflect the density of the wood that is used for distillations in Faliarivo. Moreover, because wood was collected by the still employees, rather than purchased from a sustainable wood plantation, it was loose, rather than stacked in cubic meters. As a result, it was impossible to precisely measure the density associated with a volume of wood and empty space. Beyond limitations of circumstance, the sample size of wood measured was too small to draw any conclusions on the density of the wood across the species. The standard deviation, 75, further indicates that the experimental results were inconclusive.

The Food and Agriculture Organization of the United Nations (FAO) reports that a cubic meter of plantation grown, partly seasoned Eucalyptus has a density of 600 to 700 kg/m^3. This value is 20% to 40% larger than the experimentally determined density of 506.2 kg/m^3. Moreover, given a species-specific NCV range of Eucalyptus of 19.0 to 19.6 MJ/kg, a range which is almost entirely larger than the general range for virgin deciduous woods, daily energy demand could range from 15,960 MJ to 27,440 MJ (Heat Content). Yearly energy demand could range from 2.0 million MJ to 3.8 million MJ. While this range is wider than that which was experimentally determined, all values within it are greater than the maximum of the experimentally determined range. As a result, one could conclude that the results of this study underestimate the fuel demand for the still. Moreover, these results also indicate that the energy demand of the still varies significantly from distillation to distillation. Hence, the minimum possible quantity of biogas would have to meet the maximum possible energy demand of the still (27,440 MJ/day, or 2.0 million MJ/year) or sufficient quantities of firewood would have to be available to supplement the gap in energy demand and energy supply.

Feedstock Availability

Kitchen Waste

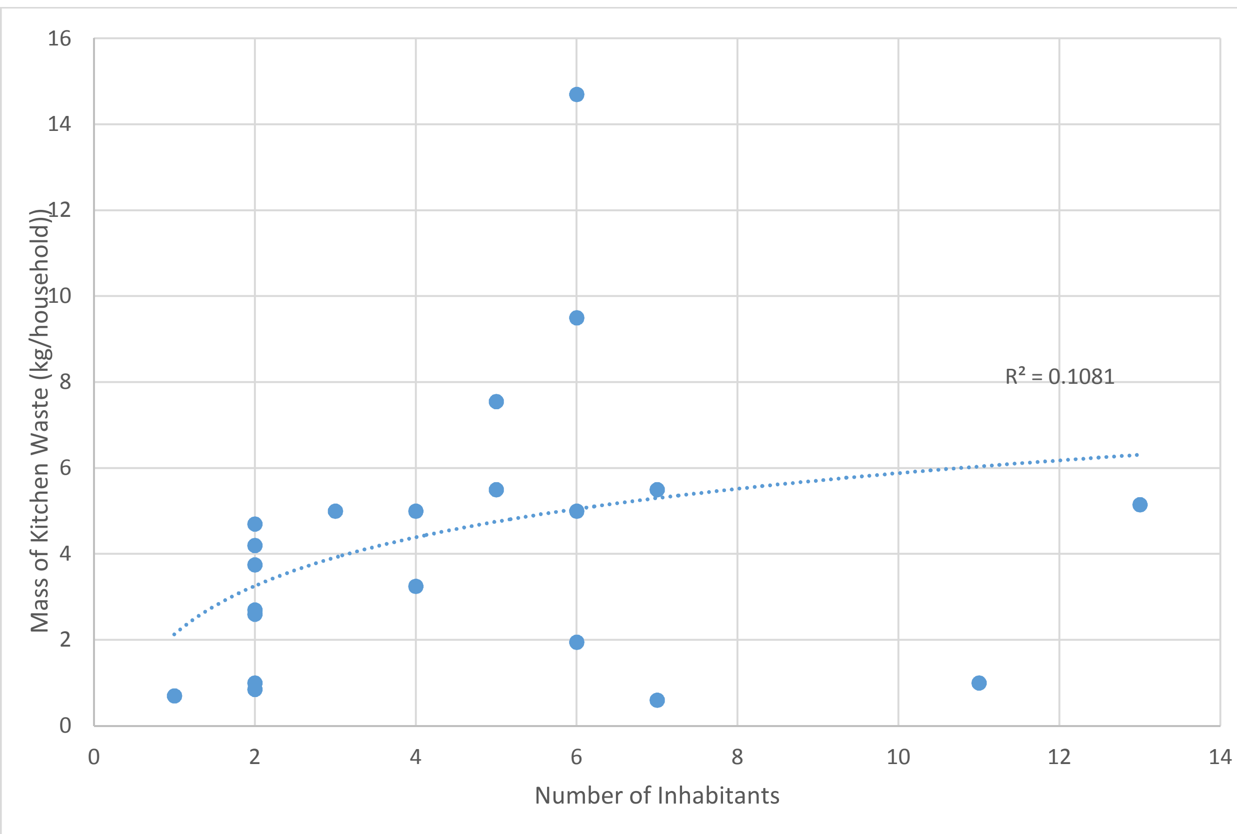
Available Biomass

The available kitchen waste was determined on the basis of the population of Faliarivo and on the average mass of kitchen waste per capita. The population estimate was based on a count of houses in the village and on a random survey of the number of individuals per household. Each of these figures introduced the potential for error. The count of houses in Faliarivo, although it excluded empty buildings and external kitchens, did not account for households with multiple houses. Frequently, families would have multiple one- or two-room huts. Therefore, it is likely that the population calculated is an overestimate since there are likely more houses than households. Secondly, while the survey selected households randomly, it could only include those with an individual who was at home at the time of the survey. As a result, it excluded families where all individuals were working or travelling, and gave preference to families who had the financial or man-power capacity to allow one or more individuals to remain at the house during the day. This is also likely to produce an overestimate in the population estimate since households with more individuals are more likely to have one or more individual in the home at all times.

Furthermore, seven households were interviewed who were not randomly selected. These families were chosen because they owned pigs. As a result, they likely represent a more affluent portion of the population. They were included within the results for two reasons. First, due to the small size of the village of Faliarivo, it is likely that one or more would have been chosen randomly for the structured survey had they not previously been included. Second, because these households represented greater wealth, they are more likely to have the time and resources at their disposal to participate in a biogas project. As a result, their responses were of particular interest in attempting to ascertain the aspects of a successful biogas project.

The second component of the measured available kitchen waste was the average mass of kitchen waste per capita. A standard deviation of 0.71 for an average per capita mass of 1.09 suggests that the average is not conclusive. The sample size is likely not large enough to draw any conclusions. Furthermore, seasonal variations in kitchen waste mean that the quantity of biomass is likely to change throughout the year. For example, at the time of the study, litchis were in season, resulting in large quantities of litchi pits and skins in the kitchen waste. Lastly, the bias in random selection which likely effected the population count could have affected the estimated average per capita mass of kitchen waste. Large families may result in lower quantities of waste per capita because the additional waste resulting from feeding another person decreases with each additional person. However, this bias is not born out in results. The logarithmic best fit curve for the graph of mass of kitchen waste per household versus the number of inhabitants has an R^2 value of 0.1, demonstrating that there is little to no correlation between the number of inhabitants in a household and the mass of kitchen waste produced [figure 8].

Figure 8: Correlation between Mass of Kitchen Waste per Household and Habitancy Levels



In the future, the mass of kitchen waste per household, per region, and per capita should be measured across multiple seasons and across a larger sample size.

Social Feasibility

The responses to the structured survey indicated a general willingness to contribute kitchen waste to the production of biogas. Once more, the structured survey inherently targeted those households who could afford to have one or more person at home during the day. These households may also be those which were more willing and able to participate in a biogas project due to the lack of significant economic or man-power barriers. This hypothesis is supported by the significant perception in the village that the study was paying individuals for their kitchen waste due to the practice of giving participating households a cup of rice in exchange for their time. As a result, the social feasibility of utilizing kitchen waste to produce biogas may be overestimated. Furthermore, a program which wishes to engage a larger proportion of the village population would likely have to address questions about participant compensation.

Survey results suggest that a biogas program which used kitchen waste as a biomass source would have to implement a kitchen waste recovery program. The significant number of participants (68%) who disposed of their kitchen waste outside indicates that outdoor disposal of waste is likely habitual and cultural. Although 95% (20 out of 21) of those who disposed of their waste outside stated that they would be willing to use a public dump to contribute to the production of biogas, levels of willingness should not be confused with success rates. This conclusion is further supported by the decrease in the proportion of individuals willing to use a public dump if it was located closer to the still. While 81% of participants stated that they would use a dump located near the still, the 14 point reduction in willingness due to the distance suggests that participation is inversely correlated with the distance to the still.

Moreover, it is possible that the large percentage of individuals who asserted their willingness to use a public dump was influenced by the fact that the interview was conducted by a white *vazaha*, or stranger, and a *vazaha* translator. In Faliarivo, *vazaha* are perceived as affluent individuals who implement development projects. As a result, when interviewed by *vazaha*, it is possible that individuals exaggerated their willingness to participate in the project in an attempt to meet the necessary conditions for a development project to be implemented.

In order to maximize participation in a biogas project, survey results suggest that any kitchen waste recovery program should be targeted at women. The significant portion of those who cooked meals who were the wife in a relationship (66%) and the higher proportion who were women indicates that women are predominantly responsible for the generation and disposal of kitchen waste. In the future, research should focus on what factors influence the disposal site of kitchen waste in an attempt to determine how to shift the site toward a public dump.

Zebu Dung

Available Biomass

The quantity of available biomass was calculated on the basis of the average number of zebu droppings and the average mass of zebu droppings. Each of these values introduced error into the final calculation. The average number of fresh zebu droppings was calculated after three surveys of the public enclosure. Between these three surveys, conducted over four days, between 37 and 92 fresh zebu droppings were counted. This large range and small sample size indicates that no conclusions can be drawn as to the average number of fresh zebu droppings produced each night. Furthermore, within those three samples, bias in counting further effected results. Certain regions within the enclosure were challenging to reach on foot, although it was evident that one or more zebu had spent time in that region. Furthermore, grassy regions of the enclosure concealed zebu droppings, further reducing the number of fresh zebu droppings that were accessible to count. As a result, it is likely that the average number of fresh zebu droppings per night is an underestimate.

The average mass of zebu droppings was similarly biased. The average mass was 1.2 kg, and the data had a standard deviation of 0.74, indicating that no conclusions could be drawn. Furthermore, due to the challenges of reaching certain regions of the enclosure on foot, or of finding zebu droppings in grassy areas, there was a bias toward choosing larger droppings which were easier to see. As a result, the average is likely an overestimate. Since the number of fresh zebu droppings per night was likely underestimated, the direction of the error in the total available biomass is indeterminate.

To determine the direction of the error, the calculated value of the quantity of available biomass can be compared to literature reported values. The biogas energy per animal unit per day for fattened cattle was reported to be 25.7 thousand BTU, or 27.1 MJ (Kossman Vol. 2. N.d.). Assuming that half of all zebu excrement, and therefore half of all biogas energy per animal, is produced during the 12 hours in which the cattle are held in the enclosure, 13.6 MJ of biogas energy per animal would be available for biogas production in Faliarivo. Since 31 zebu of various live weights were counted to use the public enclosure, 421.6 MJ of biogas energy could be generated each day, or 153,884 MJ/year. While these quantities are likely to be overestimates since the zebu in Faliarivo were not "fattened cattle," but rather thin enough as to have visible ribs, resulting in smaller droppings, these results are still significantly larger than the maximum values (93.31 MJ/day and 34,059 MJ/year) estimated by the study. In future studies, zebu should be observed overnight to determine the nightly mass of dung produced.

Social Feasibility

Since only 4 of 28 (14%) surveyed households stated that they currently used or would use in the future the public enclosure, the surveyed population was not representative of the population of interest for a biogas project which would utilize zebu dung as a biomass source. However, the willingness amongst those four individuals to move the public enclosure closer to the still (75% agreeing, with the fourth stipulating that he would use it if a modern enclosure was constructed) suggests that the enclosure could be moved to facilitate the collection of dung. If the enclosure was moved, it may be beneficial to construct an enclosure with a concrete floor sloping toward the biodigester to facilitate the collection of manure, maximize the quantity of dung and urine collected (thereby maximizing the quantity of biogas produced), and incentivize zebu owners to use the enclosure (Kossmann Vol. 1 n.d). In the future, a survey should be conducted which targets zebu owners who use the public enclosure to ascertain their attitudes toward biogas and various biomass collection procedures.

Pig Dung

Available Biomass

The available quantity of pig dung was determined on the basis of the number of households in Faliarivo, the fraction of pig owners in a random sample, the average number of pigs owned by a household, and the average weight of pig droppings. Each of these components introduces error into the final value. As previously discussed, the estimated number of households in Faliarivo is likely an overestimate. Furthermore, because seven pig owners were interviewed outside of the random structured survey, they were excluded from the random survey, reducing the number of pig owners which could be randomly selected. As a result, the fraction of pig owners in the random sample may be an underestimate. Because the estimate of the population of the pigs is inconclusive, it cannot be used with literature reported values of biogas production per pig, as was done with the zebu.

For both the average number of pigs and the average weight of pig droppings, the sample size was too small to draw conclusions. The average number of pigs per household was determined from eight households. The standard deviation was 1.3 for an average value of 2, indicating that the average number of pigs per household is not a conclusive result. Similarly, the average weight of dung was calculated from only 3 samples and 9 pigs, resulting in a sample size which was too small to draw conclusions from.

In the future, more research needs to be conducted to determine the pig population in Faliarivo and the amount of biomass which is produced and accessible for collection. This research is particularly valuable in the wake of the pig pestilence as the people of Faliarivo re-establish the pig population.

Social Feasibility

Despite the willingness of interviewed individuals to allow the employees of the still to collect pig droppings (80%), the challenge of collecting pig manure on a regular basis impedes the use of pig dung for the production of biogas. Because most pigs roam free during the day, much of the feces produced are not retrievable. However, because pig dung is a productive source of biogas, it may be desirable for COBA to invest in several pigs and a pig sty next to the still. The sty could funnel urine and feces directly into a biodigester to facilitate collection, maximize the quantity collected, and minimize staff costs.

Biogas Availability

To determine if biogas could be used as an alternative fuel source for the essential oils still in Faliarivo, the maximum energy demand must be compared to the minimum energy supply. By considering and preparing for the extreme case, all other conditions will be encompassed. Furthermore, it is likely that the minimum energy supply still overestimates that which would be produced in reality since calculations did not account for non-participation by the people of Faliarivo.

The maximum energy demand would be 15,550 MJ/day, or 2.1 million MJ/year. The minimum energy produced from biogas would be 620 MJ/day, or 226,216 MJ/year. As a result, in the extreme case, biogas produced from kitchen waste, zebu dung, and pig dung could fulfill up to 4% of the daily energy demand and 11% of the yearly energy demand. The differential between daily and yearly results reveals that by producing biogas throughout the year, excess biogas could be stored to meet demand during the operating season. Moreover, by supplementing the feedstock with other sources of organic matter, such as green matter, the amount of biogas produced could be increased. Future research should investigate the possibility of using other sources of biomass in a biodigester.

It is worth mentioning that in less extreme cases, biogas may be able to meet the energy demand of the still. These results are promising, and suggest that research efforts should focus on maximizing biogas output and minimizing still energy consumption. To minimize still energy consumption, additional energy efficiency measures should be pursued, such as insulating the still.

V. Conclusions

A biodigester supplied with the quantities of kitchen waste, zebu dung, and pig dung that are currently physically and socially available in Faliarivo would only be able to supply 4% of the daily energy demand of the still in the extreme case that biogas production was minimized and energy consumption was maximized. As a result, at this moment in time, it is not advisable to pursue biogas as an alternative source of fuel. However, it is promising that the population supported the creation of a biodigester, and that in less extreme cases, biogas may be able to meet most or all of the energy demand of the still. As a result, it is recommended that research on biogas continue, focusing on measures which could maximize the production of biogas and minimize the energy consumption of the still. In particular, alternative sources of biomass should be considered, and additional measures to maximize the energy efficiency of the still should be considered. Additionally, numerous individuals from Faliarivo expressed an interest in using biogas as a fuel for cooking. Moreover, because household energy demand is lower than that of the still, household biogas projects may be more feasible in the short term. These projects could produce similar benefits for the community and environment.

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Appendices

A. Structured Survey

A1. Survey Description

Pour comprendre s'il est possible à utiliser le biogaz à Faliarivo, je veux savoir si les gens ici sont disposés à l'idée. Les questions ici demandent au sujet de votre identité, votre connaissance de biogaz, et vos sentiments sur trois sources de biogaz. Si vous choisissez à participer, vous aurez le choix de ne pas répondre à une question si vous ne voulez pas. Vous pouvez aussi arrêter l'enquête. Toutes vos réponses seront anonymes.

A2. Structured Survey

I. Les Données Démographiques

1. Par Hasard ?	OUI	NON
2. L'Heure	MATIN	APRES-MIDI
3. Région	_____	
4. Gendre	MALE	FEMELLE
5. Age	_____	
6. Travail	a. Cultivateur b. Eleveur c. Main d'Œuvre d. Vendeur e. Autre :	
7. Etat civil	a. Marié(e) b. Divorcé(e) c. Célibataire d. Fiancé(e)	
8. Nombre d'enfants	_____	
9. Nombre de gens qui habitent chez vous	_____	

II. Le Biogaz

1. Connaissez-vous qu'est-ce que c'est le biogaz ? Si NON, lis la description.	OUI	NON
2. Connaissez-vous comment on produit le biogaz ? Si NON, lis la description.	OUI	NON

III. Les Déchets Ménagères

1. Qui fait la cuisine chez vous ?	a. Moi b. Ma femme c. Quelqu'un payé d. Autre :	
2. Où met-elle/il les déchets ménagers ?	a. La poubelle commune b. Une poubelle privée c. Au dehors d. Autre :	
(i) Si (b), (c), ou (d), seriez-vous/serait-elle disposé(e) à mettre les déchets ménagers dans une poubelle commune pour faire du biogaz ?	OUI	NON
(ii) Si (a), seriez-vous/serait-elle disposé(e) à autoriser les employés de l'alambic à ramasser les déchets ménagers de la poubelle commune pour faire du biogaz ?	OUI	NON
3. Seriez-vous/serait-elle disposé à mettre la poubelle commune plus près de l'alambic ?	OUI	NON
4. Seriez-vous/serait-elle disposé(e) à garder vos/ses déchets ménagers d'une journée ?	OUI	NON

IV. Les Lisiers des Zébus

1. Avez-vous des zébus ?	OUI	NON
Si OUI :		
2. Combien de zébus avez-vous ?		
3. Où dorment-ils les zébus?	a. Le parc public b. Autre :	
(i) Si (b), seriez-vous disposé(e) à utiliser un parc public pour faire du biogaz ?	OUI	NON
4. Est-ce que vous utilisez les lisiers des zébus ?	OUI	NON
(i) Si OUI, comment ?	a. Engrais b. Autre :	
5. Seriez-vous disposé à autoriser les employés de l'alambic à ramasser les lisiers des zébus pour faire du biogaz ?	OUI	NON
6. Seriez-vous disposé à mettre le parc des zébus plus près de l'alambic ?	OUI	NON

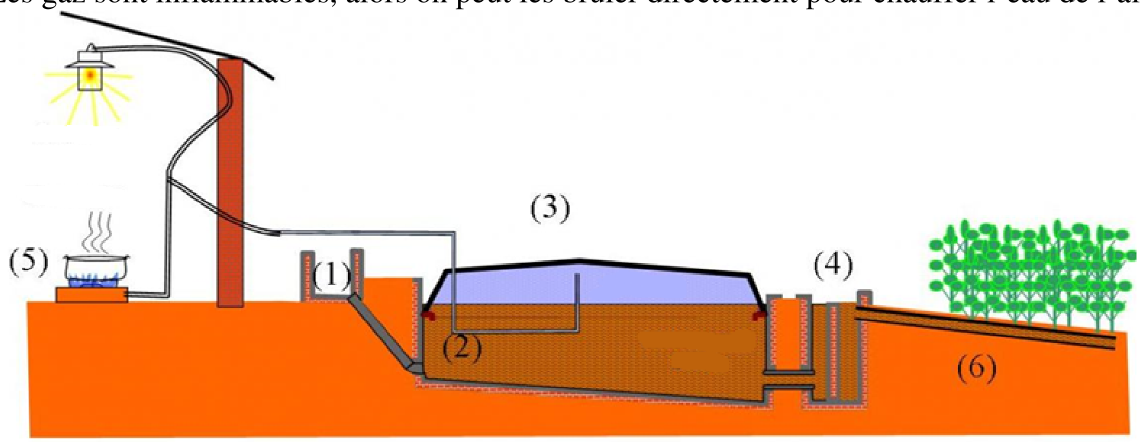
V. Les Lisiers des Cochons

1. Avez-vous des cochons ?	OUI	NON
Si OUI :		
2. Combien de cochons avez-vous ?		

3. Où dorment-ils les cochons ?	(a) Près de la maison (b) Autre :	
4. Est-ce que vous utilisez les lisiers des cochons ?	OUI	NON
(i) Si OUI, comment ?	a. Engrais b. Autre :	
5. Seriez-vous disposé à autoriser les employés de l'alambic à ramasser les lisiers des cochons pour faire du biogaz ?	OUI	NON

A3. Biogas Description

Le biogaz est une forme d'énergie renouvelable qui utilise les matériaux organiques, comme les déchets ménagers, les lisiers des zébus, ou les mauvaises herbes. On les laisse décomposer dans un récipient sous la terre. Quand les conditions nécessaires sont présentes, le processus de la décomposition produit les gaz et l'engrais. Les gaz sont inflammables, alors on peut les bruler directement pour chauffer l'eau de l'alambic.



A4. Table::Demographic Data

	Randomized	Time (AM or PM)	Region	Gender	Age	Work	Marital Status	Number of Children	Inhabitants in Household	Do you know what biogas is?	Do you know how biogas is made?
1	N	PM	3	F	50-60	A	A	9	5	N	
2	Y	PM	1	M	20-30	C	D	0	2	Y	N
3	Y	PM	1	M	40-50	E	A	8	6	N	
4	Y	PM	1	F	20-30	E	A	2	9	N	
5	N	PM	1	M	40-50	A, B	A	11	12	N	
6	N	PM	2	F	20-30	D, E	A	1	3	N	
7	N	PM	2	M	30-40	B	A	8	13	Y	N
8	N	PM	2	F	20-30	D, E	C	0	1	N	
9	Y	PM	2	F	30-40	A	C	1	4	N	
10	Y	PM	2	F	20-30	A	C	0	4	N	
11	Y	PM	2	M	20-30	D	C	0	2	N	
12	Y	PM	2	F	40-50	A, D	A	6	11	N	
13	N	PM	5	F	40-50	A	A	5	7	N	
14	N	PM	1	M	40-50	A	A	4	10	N	
15	Y	AM	1	M	40-50	A, D	A	7	8	N	
16	Y	AM	3	F	40-50	A, E	B	7	5	N	
17	Y	AM	3	F	50-60	A	A	8	13	N	
18	Y	AM	4	F	20-30	A	C	1	2	N	
19	Y	PM	4	M	20-30	E	A	4	7	N	
20	Y	PM	4	F	40-50	A, C	A	7	7	N	
21	Y	PM	4	F	20-30	A	B	4	5	N	
22	Y	PM	4	M	40-50	C, E	A	1	3	Y	N
23	Y	AM	4	M	40-50	A	A	4	6	N	
24	Y	AM	4	F	50-60	A	B	8	4	N	
25	Y	PM	4	M	40-50	A, D	A	5	6	N	
26	Y	PM	4	F	40-50	A	C	6	5	N	
27	Y	PM	4	F	20-30	A	C	0	3	N	
28	Y	PM	4	F	20-30	A	C	2	2	N	

B. Fuel Demand

B1. Table: Weight and Dimensions of Firewood

	Length	Diameter 1	Diameter 2	Diameter 3	Diameter 4	Diameter 5	Weight
1	80	14.5 5	13.5 4.5	9 3	9 3	8 2	1.5
2	83	2.5 1.5	10 6.1	6.3 4.5	6.5 6.1	7 6	1.5
3	68	7.3 7.1	5.8 6	6.1 5.9	7.5 5.7	7.5 5.8	1.2
4	69.6	2 3	12.5 7.9	12.5 8.6	10 5.8	11.5 4.3	2.15
5	106.5	7.6 5.2	8.7 4.6	7.2 4.6	6.5 5.1	4.5 5.6	1.6
6	59.2	6.1 5	7.1 6.4	7 5.4	6.4 4.5	5 4.8	1
7	70.6	5 3.9	5.4 3.9	6 4.3	6.8 4.4	5.2 4.1	0.8
8	77.5	7 3	8.8 4.3	11.1 5	11.1 4.7	4.1 1.9	1.45
9	78.7	5 1.7	13 6.1	12.4 4.5	10.4 6.2	8.8 3.8	2.1
10	83.8	2.5 1.5	9.9 4.8	6.1 4	6 5.3	3.5 3.2	1.55
11	59.1	5.9 4	6 4	5.7 3.9	5.1 3.9	3.8 3.6	0.7
12	82.6	6.5 6.8	7.9 7.3	6.7 6	6.1 6.7	3.1 6	2.1
13	75.4	6 5.1	8 5.8	7.9 5.9	7.8 8.5	2.7 1.9	1.6
Average	76.5	6.0 4.1	9.0 5.5	8.0 5.0	7.6 5.4	5.7 4.1	1.5
Standard Deviation	12.3	3.2 1.9	2.7 1.3	2.5 1.4	1.9 1.4	2.6 1.5	0.5

B2. Table: Volume of Wood Modeled with 5 Pyramidal Frustums

	Weight (kg)	Volume of Segment 1 (cm³)	Volume of Segment 2 (cm³)	Volume of Segment 3 (cm³)	Volume of Segment 4 (cm³)	Total Volume (cm³)	Total Volume (m³)	Density (kg/m³)
1	1.5	1330.8	855.0	540.0	425.2	3151.0	0.0032	476.0
2	1.5	552.5	905.6	702.2	847.0	3007.3	0.0030	498.8
3	1.2	731.6	601.7	668.5	733.1	2734.8	0.0027	438.8
4	2.15	748.7	1793.8	1417.9	933.8	4894.3	0.0049	439.3
5	1.6	1058.9	972.2	882.2	774.4	3687.7	0.0037	433.9
6	1	558.3	615.1	491.3	390.2	2054.9	0.0021	486.6
7	0.8	357.9	412.8	491.3	450.1	1712.0	0.0017	467.3
8	1.45	562.1	898.8	1042.9	517.4	3021.2	0.0030	479.9
9	2.1	746.1	1322.3	1182.2	946.7	4197.3	0.0042	500.3
10	1.55	451.3	740.0	587.0	432.1	2210.4	0.0022	701.2
11	0.7	351.6	341.4	311.0	246.6	1250.7	0.0013	559.7
12	2.1	1048.7	1005.1	837.0	599.1	3490.0	0.0035	601.7
13	1.6	720.6	876.6	1058.7	564.7	3220.6	0.0032	496.8
Average	**1.5**	**709.1**	**872.4**	**785.6**	**604.6**	**2971.7**	**0.0030**	**506.2**
Standard Deviation	**0.5**	**290.7**	**379.8**	**320.0**	**223.4**	**1004.3**	**0.0**	**75.3**

B3. Table: Distillation Materials and Demand

Material	Quantity per Distillation	Notes
Wood	0.35 - 0.5 m^3	The quantity of wood required depends on its quality. If the wood is wet, the distillation requires more wood. The reverse is true for dried wood. The still at Faliarivo uses sustainably sourced eucalyptus, litchee, and mango wood.
Water	No response	
Ravintsara	200 - 250 kg	For the best quality of oil, fresh and ripe leaves that are dried for 12 hours in the shade are used.
Essential Oil	0.8 kg / 100 kg Ravintsara (average)	
Distillation Time	2.5 - 3.0 heures	
Broiler Time	3.5 - 4.0 heures	

C. Feedstock Availability

C1. Table: Biomass Sources in Faliarivo

Biomass	Classification
Zebu Manure	B
Pig Manure	B
Vakoka (Invasive Plant)	A
Harongana (Invasive Plant)	A
Albeza (Invasive Plant)	A
Kitchen Waste	W
Weeds	A
Ravintsara Waste	A
Toaka Gasy Sugarcane Waste	A
Old Rice Plants	A

Kitchen Waste

Available Biomass

C2. Table: Mass of Kitchen Waste per Capita

Date	Number of Inhabitants	Region	Total Weight	Weight of Container	Weight of Waste	Mass of Kitchen Waste per Capita
10-Nov	5	3	6.1	0.6	5.5	1.10
11-Nov	2	1	3.75	0	3.75	1.88
11-Nov	6	1	9.5	0	9.5	1.58
11-Nov	2	1	4.2	0	4.2	2.10
11-Nov	6	1	1.95	0	1.95	0.33
12-Nov	2	1	4.7	0	4.7	2.35
12-Nov	1	2	0.8	0.1	0.7	0.70
12-Nov	4	2	5	0	5	1.25
12-Nov	11	2	1.1	0.1	1	0.09
12-Nov	2	2	3.6	1	2.6	1.30
13-Nov	5	3	7.75	0.2	7.55	1.51
13-Nov	13	3	5.15	0	5.15	0.40
13-Nov	2	4	0.85	0	0.85	0.43
13-Nov	7	4	5.7	0.2	5.5	0.79
13-Nov	7	4	0.6	0	0.6	0.09
13-Nov	5	4	3.4	0.5	2.9	0.58
13-Nov	3	4	5	0	5	1.67
14-Nov	4	4	3.25	0	3.25	0.81
14-Nov	6	4	14.8	0.1	14.7	2.45
14-Nov	2	4	2.7	0	2.7	1.35
14-Nov	6	4	5	0	5	0.83
14-Nov	2	4	1.1	0.1	1	0.50
Average						**1.09**
Standard Deviation						**0.71**

C3. Table: Population Estimate

Region	Description	Number of Houses	Average Number of Inhabitants	Estimated Population
1	North	81	8	635
2	Market	60	6	340
3	Center	20	8	153
4	South	83	5	377
5	Far South	5	7	35
Total		**249**		**1540**

Social Feasibility

C4. Table: Kitchen Waste Structured Survey

Respondent	Qui fait la cuisine chez vous?	Où met-elle/il les déchets ménagers ?	Si (b), (c), ou (d), seriez-vous/serait-elle disposé(e) à mettre les déchets ménagers dans une poubelle commune pour faire du biogaz ?	Si (a), seriez-vous/serait-elle disposé(e) à autoriser les employés de l'alambic à ramasser les déchets ménagers de la poubelle commune pour faire du biogaz ?	Seriez-vous/serait-elle disposé(e) à mettre la poubelle commune plus près de l'alambic ?	Seriez-vous/serait-elle disposé(e) à garder vos/ses déchets ménagers d'une journée ?	Notes
1	D	B	O		N	O	D: Sa grand-fille; L'alambic est loin de sa maison, les employés de l'alambic devrait ramasser les déchets ménagers.
2	A, D	B	O		O	O	
3	B	A, C, D		O	O	O	E: Le pasteur; D: Aux zébus
4	A, C	B	O		O	O	E: L'instutrice de l'école public
5	B	C, D	O		N		D: Aux zébus; L'alambic est trop loin de sa maison, mais si quelqu'un lui donne de l'argent, peut-être il peut utiliser une poubelle public près de l'alambic.
6	A	C	O		O		Elle serait disposée a mettre la poubelle public plus près de l'alambic si tous les villageois était d'accord.
7	B	C	O		O		
8	A	C	O		O	O	
9	A	C	O		O	O	
10	D	C	O		O	O	D: Sa soeur

Respondent	Qui fait la cuisine chez vous?	Où met-elle/il les déchets ménagers ?	Si (b), (c), ou (d), seriez-vous/serait-elle disposé(e) à mettre les déchets ménagers dans une poubelle commune pour faire du biogaz ?	Si (a), seriez-vous/serait-elle disposé(e) à autoriser les employés de l'alambic à ramasser les déchets ménagers de la poubelle commune pour faire du biogaz ?	Seriez-vous/serait-elle disposé(e) à mettre la poubelle commune plus près de l'alambic ?	Seriez-vous/serait-elle disposé(e) à garder vos/ses déchets ménagers d'une journée ?	Notes
12	A, D	C	O		N	O	L'alambic est trop loin de sa maison.
13	A	C	N		N/A		Elle habite loin du village, alors une poubelle public serait trop loin. Mais, si quelqu'un la payait, elle serait disposée à utiliser une poubelle public. Même si les employés de l'alambic venaient chez elle pour ramasser les déchets ménagers, elle serait disposé.
14	B, D	A		N	O		Il n'autorise pas les employés de l'alambic à ramasser les déchets de la poubelle public actuelle car il a peur que le trou grossisse. Mais, si quelqu'un construisait une nouvelle poubelle, il l'autoriserait.
15	B	C	O		O		
16	A	C	O		O	O	
17	A	C	O		N	O	L'alambic est trop loin de sa maison.
18	A	C	O		O	O	
19	B	C	O		O	O	
20	D	C	O		O	O	D: Sa fille

Respondent	Qui fait la cuisine chez vous?	Où met-elle/il les déchets ménagers ?	Si (b), (c), ou (d), seriez-vous/serait-elle disposé(e) à mettre les déchets ménagers dans une poubelle commune pour faire du biogaz ?	Si (a), seriez-vous/serait-elle disposé(e) à autoriser les employés de l'alambic à ramasser les déchets ménagers de la poubelle commune pour faire du biogaz ?	Seriez-vous/serait-elle disposé(e) à mettre la poubelle commune plus près de l'alambic ?	Seriez-vous/serait-elle disposé(e) à garder vos/ses déchets ménagers d'une journée ?	Notes
21	A	A		O	O	O	
22	B	C	O		O	O	
23	B	C	O		O	O	Il a dit que les gens qui habitent loin du village ne peuvent pas porter leurs déchets ménagers.
24	D	B	O		O	O	D: Sa fille
25	B	C	O		O	O	D: Vendeur de l'alcool
26	D	C	O		O	O	D: Sa fille
27	A	C	O		O	O	
28	A	C	O		O	O	

Zebu Dung

Available Biomass

C5. Table: Nightly Quantity of Fresh Zebu Droppings

Date	Number of Fresh Zebu Droppings
11-Nov	92
13-Nov	79
14-Nov	37
Average	**69**
Standard Deviation	**29**

C6. Table: Average Mass of Fresh Zebu Dung

Date	Weight (kg)
10-Nov	2.8
10-Nov	1.7
10-Nov	2.05
10-Nov	0.6
10-Nov	0.7
11-Nov	0.65
11-Nov	2
11-Nov	0.1
11-Nov	2.15
11-Nov	0.35
13-Nov	0.45
13-Nov	1.1
13-Nov	1.8
13-Nov	0.15
13-Nov	1.6
14-Nov	0.8
14-Nov	1.2
14-Nov	1.5
14-Nov	1.05
14-Nov	1.15
Average	**1.195**
Standard Deviation	**0.74**