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# Sustainability Approach

## Food Waste-to-Energy Solutions for Small Rural Developing Communities

SHAKIRA R. HOBBS, EVVAN V. MORTON, NICOLE BARCLAY, AND AMY E. LANDIS

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# Sustainability Approach: Food Waste-to-Energy Solutions for Small Rural Developing Communities

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*Abstract: The primary objective of this research is to show how waste-to-energy solutions can be introduced to small rural developing communities, while employing unique methods of community engagement and using the three pillars of sustainability to guide decisions. Waste management provides unique challenges to developing communities with no formally established way of disposing waste. It requires a revamping of social norms to develop a waste management system that the community accepts and also provides safe, efficient disposal. Thus, it is essential to understand how economics, energy, environment, community acceptance, and community engagement interact in the creation and employment of waste-to-energy systems in developing communities. A multiphase and mixed-methods research approach was employed in Sittee River, Belize that included waste audits, waste reduction modeling, and community interviews. The waste audits quantified the amount of food waste generated by the community and evaluated whether or not waste could be used to meet local school cooking needs. The USEPA's waste reduction model (WARM) quantified and compared the amount of greenhouse gases associated with burying, burning, river dumping, and anaerobic digestion of food waste. Additionally, community interviews explained the perceptions of current waste practices. While the WARM model proves the environmental advantage of using the anaerobic digester, the interviews reveal that the community does not understand the impacts of their current waste management practices. Community members are less concerned about the harmful effects of burying and burning trash, but are still interested in alternative waste management systems.*

*Keywords: Sustainability, Waste Management, Developing Countries, Waste-to-Energy, Anaerobic Digestion, Community Engagement*

## Introduction

Every year, 2.12 billion tons of waste is disposed of worldwide (The World Counts 2016) and municipal solid waste (MSW) generation is expected to double across the world by 2025 (World Bank 2010). While countries with lower income generate the least amount of waste (Khatib 2011), waste management techniques such as landfilling and recycling are not feasible. For example, many people who live in rural regions of developing countries do not have waste collection services or their own vehicles to transport their garbage to a landfill (Garfi and Bonoli 2010). In many cases, developing communities lack infrastructure, from landfills to recycling facilities to waste collection and sorting services (Barton, Issaias, and Stentiford 2008). Consequently, people living in rural communities are often left to manage waste on their own.

Burning, burying, and disposing of waste in water bodies are common waste disposal methods in many developing countries. Burning produces particulate matter and affects air quality (Christian et al. 2010). Disposal of trash in rivers or oceans results in nitrate emissions to rivers (Blacksmith Institute 2000) and threatens coastal recreational beaches and coral reefs (Rakodi, Gatabaki-Kamau, and Devas 2000). When buried, organic waste degrades and produces environmental pollutants (Babayemi and Dauda 2009). Developing countries that do have

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landfills are often burned openly with uncontrolled fires resulting in higher emissions of particulate matter compared to developed countries (Wiedinmyer, Yokelson, and Gullett 2014).

The benefits of sustainable waste-to-energy strategies go further than improving the environment and human health. About 40 percent of the waste generated in developing countries is organic (Swati 2009) and can be converted to a renewable source of energy. Waste to energy in developing countries can also increase economic development (UNEP 2010). The International Renewable Energy Agency (IRENA) (2016) report states that the use of renewables increases gross domestic product. One form of renewable energy technology is anaerobic digestion (AD)—a technology that biodegrades and stabilizes organic compounds by microorganism in anaerobic conditions leading to biogas production and biosolids that can be used as a fertilizer. Typical digester biogas is comprised of 70 percent of methane ($CH_4$) (Rittmann and McCarty 2001). A study of two citrus processing facilities in Belize found that using AD to treat citrus waste could produce about 18 million BTUs per hour, which is enough to electrify the entire facility (USAID 1991). This resulted in savings of approximately $100,000 per year. Additionally, Belize has long utilized food waste through the sugarcane processing industry, which use their waste–bagasse to produce electricity (Department 2011). AD has potential to be a sustainable option for handling and treating food waste, reducing pollution, and providing a reliable energy source and economic growth for rural communities. AD increases access and empowers community members to satisfy their essential needs.

Although there are several benefits, there are also challenges with AD as highlighted by other studies. Within rural developing communities, challenges associated with high cost and expertise in construction, installation, and maintenance inhibit its dissemination (Surendra et al. 2014). For example, in rural China, a high percentage of biogas projects have failed due to poor services during the operation of the technology (Chen et al. 2010). Similarly, lack of training caused users to abandon the use of household digesters in areas of Latin America and the Caribbean several years after they were built (Garfi et al. 2016).

Thus, it is most important that communities are engaged, empowered, and involved in the design of the technology, especially if foreigners are introducing the technology. Often times engineers are excited and enthusiastic about sharing their technical background, but unfortunately neglect to understand important factors that affect communities (Harsh et al. 2016). For example, women are often responsible for feeding the digester and cooking with the gas produced from the AD (Vögeli et al. 2014). Thus, women are typically more affected by malfunction of the AD and often do not have the tools, resources, or knowledge to maintain the AD system. It is therefore necessary to consider the potential of the digester to fail and equip the community, especially women, with tools to remediate foreseeable failures and conduct regular maintenance.

### *Sittee River Village*

Sittee River Village, located in the Stann Creek District of Belize, does not have a waste management infrastructure like many rural developing communities; there is no organized collection of waste or transport to a landfill. There are 349 residents of the village, most of whom do not own vehicles to transport trash to the nearest landfill, which is as far as 50 miles away from the village. As a result, villagers rely on burning waste, burying waste, and/or throwing trash into open bodies of water for disposal. Because schools and summer camps do not have the infrastructure to cook or refrigerate food, students are often dismissed early to allow students to go home for meals, causing students to miss out on time that could be spent in the classroom. This research evaluates whether food waste collected in the community could provide enough fuel via AD to meet primary school cooking needs.

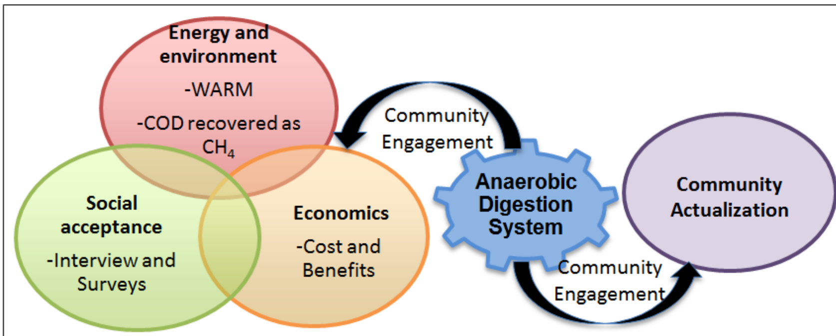
Developing an AD that converts food waste to $CH_4$ allows Sittee River Village to set a benchmark of innovation in the field of renewable technologies and waste management in developing countries. Best practices and lessons learned can be developed from this project to inform other rural communities and developing countries and contribute to their nation's sustainability goals.

### *Research Objective*

This article focuses on evaluating the feasibility of a low-cost AD system for a local primary school in Sittee River Village. The amount of food waste produced from homes and resorts was quantified via waste audits to estimate the amount of cooking fuel that could be produced locally. The objective of this study was to evaluate the three pillars of sustainability and actively involve community members in the design process leading to actualization. The economic pillar was addressed by investigating the costs of AD implementation and maintenance. The society pillar was addressed by assessing the community's perception of their current waste management and AD. The environmental pillar was addressed by assessing the greenhouse gas (GHG) emissions and waste generation of current and new waste management strategies.

## Methods

A multi-phase sustainability approach was taken to assess the feasibility of utilizing AD as a way to manage waste, understand the community's perception of waste in their village, reduce pollution, and provide an additional source of energy for Sittee River Village, Belize. The three pillars of sustainability: environment (including energy and GHG emissions), economics, and social acceptance were evaluated to determine system sustainability. Throughout the process, the community was engaged in the design of the system that ultimately leads to sustainable community practice, maintenance, and ownership of the AD (Figure 1). For this study we conducted a waste audit to quantify the amount of waste available for AD and the associated environmental impacts. The $CH_4$ production from AD was estimated using its electron equivalent energy recovery as equivalent chemical oxygen demand (COD). Interviews with local community members were conducted to assess their knowledge, understanding, and perceptions of current and future waste management techniques.




Energy from AD and environmental impacts of AD are quantified by calculating the chemical oxygen demand recovered as $CH_4$ and by using EPA's WARM. The cost benefits of using $CH_4$ from AD are compared to purchasing $C_4H_{10}$. Surveying and interviewing villagers' perception of the AD measures social acceptance. Community members are engaged throughout the design process leading to future installation of AD. AD = anaerobic digester.

Figure 1: Sustainability approach for waste-to-energy solutions
*Source: Hobbs, Morton, Barclay, and Landis*

### *Waste Audit*

A waste audit of Sittee River Village quantified the amount of food waste produced in the village by an average household; the audit tracked waste over the course of one week in August 7–12, 2016. There are 349 residents of the village, and, as such, waste from the entire community could not be tracked. Therefore, the waste audit collected a representative sample from five of households that consisted of two to seven people (representing 5% of all households, 1% of the population) and one resort that serviced forty-two occupants (representing 13% of the resorts in the village).

During the waste audit, trash was collected by the residents in households and by kitchen staff at the resort. Each household and resort was supplied with a new garbage bag each day for the duration of the collection. The residents and kitchen staff were asked to fill their garbage bag with any food waste they would usually dispose of in the trash until they receive a new garbage bag from the research team the next day to repeat the process.

The research team collected the waste from the residents and resort once a day for five days. Following collection, contents were sorted by first removing inorganic material such as plastic wrappings and aluminum cans. Next, types of food waste, shown in Table 1, were sorted. The mixed food waste was weighed using a digital scale (Vivitar BodyPro PS-V132). The quantity of food waste produced from each family and resort is summarized in Table 1.

Table 1: Amount of food waste collected from households and a resort in Sittee River Village for one week.

| Households /Resort | Food waste (kg/week) | # of people | Type of food waste |
|---|---|---|---|
| **Household 1** | 9.9 | 4 | plantains, rice, ramen, jack fruit, potato salad, bread, mixed vegetables |
| **Household 2** | 4.5 | 2 | rice, chicken, avocado, macaroni |
| **Household 3** | 2.2 | 7 | banana peels, cabbage, cassava skin, plantain, corn stover, mango peels, lemon |
| **Household 4** | 22.7 | 4 | watermelon peels, banana peels, rice, beans, breadfruit, mamey peels, papaya peels, onion, beets, cabbage, cucumber, Johnny cake, okra |
| **Household 5** | 2.4 | 3 | fishbone, lime, onion, green peppers, potato, cilantro, sweet peppers, chicken skin |
| **Resort 1** | 23.1 | 42 | egg shells, onion, carrot, cantaloupe, pancake, pineapple, orange peels, Johnny cakes, bread, watermelon, lemon, chicken, cabbage, lettuce, cilantro, lobster shell, fish, broccoli, tomato, flour, cucumber, rice, red pepper, plantain |
| **Total** | **64.8** | **62** | |
| ***Johnny cake, similar to pancake** | | | |
| ****Mamey, type of tropical fruit** | | | |

*Source: Hobbs, Morton, Barclay, and Landis*

The amount of food waste collected from the waste audit was used to estimate total food waste generation for one year. Using the data summarized in Table 1, village waste was estimated by assuming that the households audited are representative of the entire village households. The average waste collected from five households was 41.9 kg/house/week. There are seventy houses in the village, thus the annual waste generated in the village is 3.2 tons/week. Therefore, the functional unit for this study is 167.4 tons of waste/yr.

## *Environmental Impact—GHG Emissions*

For this study we estimate the global warming potential (GWP), measured in $CO_2$ equivalent, to quantify the amount of GHG associated with burying and AD of food waste. The GHG emissions of burying and AD of food waste were assessed using USEPA’s Waste Reduction Model (WARM). WARM was created to assist solid waste managers in environmental assessment of the end of life processes of material types and waste management practices such as landfill, combustion, recycling, composting, and AD (EPA 2016b). The model is based on US inventories of GHG emissions and allows users to select material inputs while providing conditions such as transportation and type of process of waste management technology.

All inputs for WARM were based on the waste audit. WARM has preset options for many parameters, described in Table 2. Table 2 also shows the parameters that were used in this model.

Table 2: WARM Analysis Parameters

| WARM Parameter | WARM Preset Options | Used in This Model |
|---|---|---|
| **Estimation of source reduction** | Current mix or 100% virgin material | 100% virgin material, which represents the inputs of food waste |
| **Gas emissions from landfill** | National Average, LFG Recovery or No LFG Recovery | No LFG Recovery, which represents burying food waste in Sittee River |
| **Landfill gas recovery** | Recover for energy or flare | Flare, back calculations used to estimate CO2 equivalence emitted |
| **Type of landfill gas recovery** | Default-typical operation, worst-case collection, aggressive gas collection or California regulatory collection | Default-typical operation, which represents most no gas recovery |
| **Moisture condition and associated bulk MSW decay rate** | National average, dry; k = 0.02, moderate; = 0.04, wet; k = 0.06 or bioreactor; k = 0.12 | Wet, which represents Belize's hot and humid climate |
| **Anaerobic digestion of food waste materials** | Wet digester or dry digester | Wet, which represents the selection and design of the digester |
| **Land application of digestate** | Cured or not cured | Not cured, which represent the selection and design of the digester |
| **Emissions occurring during transportation** | 20 miles or provided information | Provided information (12 miles), round-trip collection of food waste |

*Source: Hobbs, Morton, Barclay, and Landis*

The 100 percent virgin material was used to estimate source reduction. According to WARM and based on the waste audit, it is extremely unlikely for food waste to be recycled or to use recycled inputs during material production (EPA 2015).

For the burying of food waste, the WARM landfill scenario was used without landfill gas recovery to mimic the burial of food waste in Sittee River Village. Since WARM only has the option to recover $CH_4$ for energy or to flare it, the flare option was chosen. Flaring the $CH_4$ gas produces only $CO_2$ as a product, whereas burying waste produces $CO_2$ and $CH_4$. The gases produced from burying waste emit approximately 50 percent $CH_4$ and 50 percent $CO_2$ (EPA 1997). Therefore, $CH_4$ was estimated by multiplying the amount of $CO_2$ calculated from WARM by 50 percent and then multiplying by 25, since $CH_4$ is 25 times more potent (EPA 2014a), to get $CO_2$ equivalence. Finally, the $CO_2$ and $CO_2$ equivalence was combined to get the total amount of GHG associated with burying food waste.

Since gas recovery does not reflect our scenario for burying food waste, the default typical operation was chosen given that only 20 percent of landfills are capable of recovering the gas (EPA 2016a). WARM does not factor this option into the results since the flare option was selected in the previous step. The moisture content "Wet (k = 0.06)" was used to associate bulk MSW decay rate for organic waste when buried according to Belize's hot and humid climate (UNCSD 2012).

The AD process being considered for Sittee River is wet digestion where the digestate will be used as a land applied fertilizer for agriculture. Wet digesters typically produce higher $CH_4$ yields, have superior economic benefits, and require no special technology to load and unload the digester unlike dry digesters (Angelonidi and Smith 2015). Therefore, wet digestion was selected in WARM parameters. The digestate for the fertilizer will not be cured (dewatered and liquids returned to digester) given that the process is energy intensive (Al Seadi et al. 2013). In addition, digestate is typically used as a fertilizer without additional treatment (Al Seadi et al. 2013).

Transportation emissions were only considered for the AD scenario. Food waste will be collected from villagers and resorts to a central location—Sittee River Methodist Primary School. This differs from the burying scenario, since households and resorts bury waste on-site and do not require transportation. The collection distance will be twelve miles, which is the round-trip distance between the village and nearby resorts.

Other methods of food waste disposal in Sittee River include dumping waste in bodies of water and burning food waste in burn barrels. WARM's model calculates combustion from mass burn, modular and refuse-derived fuel industrial technology; thus, the GHG emissions should not be similar to those emissions for direct combustion in Belize given that simple burn barrels are used. Disposal of food waste utilizing burn barrels is not modeled in WARM and other existing tools. Similarly, disposal of waste into the river is not modeled in WARM or other existing tools, and as such no subsequent environmental impacts were estimated in this study for disposal of trash in bodies of water.

$CO_2$ emission from burning food waste is zero since it is considered to be biogenic (FAO 2013; EPA 2016b). The amount of food waste dumped into the river was estimated based on the results from the waste audit and reported directly as mass of waste.

The emissions and impacts resulting from dumping waste in water bodies were not considered in this study. The implications of these assumptions are discussed in further detail in the results.

### *Estimating Methane Production and Butane Consumption for Cooking*

To estimate the amount of $CH_4$ that can be produced from food waste via AD, the electron equivalent energy recovery [as equivalent chemical oxygen demand (COD)] was calculated according to equation 1:

(1)

$$\mathbf{1mL\ CH_4\ gas = \frac{L}{10^3\ ml} \cdot \frac{1\ mol\ CH_4}{22.4\ L} \cdot \frac{273\ K}{313\ K} \cdot \frac{8e^{-}eq}{mol\ CH_4} \cdot \frac{8\ g\ COD}{e^{-}eq} \cdot \frac{10^3 mg}{g} = 2.52mg\ COD}$$

Food waste with similar characteristics COD was measured using HACH HR COD kits (TNT 821, 20-1500 mg/L) (Elbeshbishy, Nakhla, and Hafez 2012). The concentration of the COD was used to estimate the grams of COD present in the food waste collected and converted to volume of $CH_4$ according to equation 2:

(2)

$$P_{FW} \cdot V_{FW} \cdot \frac{1\ mL\ CH_4}{2.52\ mg\ COD} = \mathbf{L\ of\ CH_4}$$

where $P_{FW}$ = food waste COD concentration (g/L), $V_{FW}$ = volume of food waste ($m^3$). To estimate the amount of fuel ($CH_4$ or $C_4H_{10}$) needed to boil water the specific heat equation was used according to equation 3:

(3)

$$Q = cm\Delta T$$

where Q = heat needed (J), c = specific heat (J/g °C), m = mass (g), ΔT = change in temperature (°C).

*Interviews*

Two visits to Sittee River village were made for this study. The initial visit occurred in June of 2015, and the second in August 2016. During the June 2015 visit, a random sample of eighteen community members (representing 7.8% of the 230 villagers) who were over the age of eighteen, were interviewed on their demographics, quality of life, energy use, trash disposal, and view of sustainability. All of the interviewees have lived in Sittee River for ten years or more, ages ranging from twenty-three to seventy-three years old, and 44 percent have a high school education. All interviews were conducted in person (IRB2016-323, exempt under category B2). The interviews were audio recorded with participants' permission and later transcribed by the interviewers. The interview questions are listed in Table 3.

Table 3: June 2015 Interview Questions

| | |
|---|---|
| **1** | What is your occupation? |
| **2** | What is your age? |
| **3** | What is the highest level of education you have completed? |
| **4** | How many years have you lived in Sittee River? |
| **5** | Do you have access to electricity? |
| **6** | What kind of fuels do you use in your home? |
| **7** | How would you rate your standard of living? |
| **8** | Is Sittee River sustainable? |
| **9** | How do you dispose of your trash? |
| **10** | Do you think the way you dispose of your trash is harmful to the environment? |
| **11** | Is there a trash collection service in your village? |

*Source: Hobbs, Morton, Barclay, and Landis*

The second visit occurred in August of 2016. Five community members were interviewed on their views of climate change and their perceptions of the environmental and health effects of how they dispose of their waste. The five people interviewed were from twenty to seventy years old. The interviewer recorded the responses by hand. The interview questions are listed in Table 4.

Table 4: August 2016 Interview Questions

| | |
|---|---|
| **1** | Have you noticed in any changes in the climate or weather in the past few years? |
| **2** | How do you dispose of your trash? |
| **3** | Do you think the way you dispose of your trash is harmful to the environment? |

*Source: Hobbs, Morton, Barclay, and Landis*

The Sittee River village council is made up of nine (one woman and eight men) elected community members who make decisions on behalf of the entire village. Two meetings were held with the council to discuss the goals for the duration of the trip and the progress that has been made before arriving to the village. One meeting was held during the 2015 visit and the other during the 2016 visit. During these meetings, the research team explained the AD project and its goal to convert food waste to energy. In 2016, the team went more into depth on the AD technology and received comments from the council on their thoughts of integrating a digester into their community. The council made suggestions such as creating a job for a community member to transport food waste from villagers and resorts to the centralized AD. The community members believe this to be feasible given that the distance will be drastically shorter to the AD than the landfill. Informal meetings with the council occurred throughout the year via email communications and Facebook messaging.

### *Social Acceptance*

Social acceptance was estimated using a Likert scale to determine the social acceptance rating of implementing an AD, burning and burying trash, and river dumping described in detail in Table 5 (Likert 1932). Sixty-one percent of the respondents of all of the interviews conducted agree that burning trash is harmful to the environment. Furthermore, the results show that none of the interviewees solely bury their trash. Trash is either burned and buried or not buried at all. Of the seventeen people in 2015 that said they burn their trash, four of them also bury it. Therefore, the research team suggests that there is questionable interest by the villagers to burn and bury their trash, giving a Likert scale rating of two. Given the enthusiastic responses from the meetings held with the village council on behalf of the entire village and interest in wanting to see a working prototype, the research team assigned a Likert scale rating of four for a positive interest in integrating a digester into the community. None of the community members interviewed said that they dump their trash in the river although it was observed; therefore a social acceptance rating of one was given for river dumping.

Table 5: Social Acceptance Rating

| **Type of Waste Management** | **Full Acceptance** | **Positive Interest** | **Neutral** | **Questioning Interest** | **No Acceptance** |
|---|---|---|---|---|---|
| AD | 5 | **4** | 3 | 2 | 1 |
| Trash Burning and Burying | 5 | 4 | 3 | **2** | 1 |
| River Dumping | 5 | 4 | 3 | 2 | **1** |

*Source: Hobbs, Morton, Barclay, and Landis*

## Results/Discussion

### *Food Waste to Energy*

If all food waste from the five homes and one resort in Sittee River Village was converted to $CH_4$ for cooking, the community could boil forty-three gallons of water for one week (Figure 2). The school's cooking needs of sixteen gallons of water per week would be exceeded by 60 percent, allowing cooked school lunches for sixty students and a surplus of $CH_4$ (Figure 2). The capital cost of building a prototype digester is $468 with a lifetime of one year. The cost of boiling sixteen gallons of water per week with $C_4H_{10}$ is $0.43, ($0.78/ft$^3$) whereas boiling sixteen gallons of water per week with $CH_4$ from food waste is $9/week. The avoided costs per year of purchasing $C_4H_{10}$ would be $22.33 and selling excess $CH_4$ would result in $43.68 annually. The payback period for using the digester, avoided cost of purchasing $C_4H_{10}$ and profit from selling excess $C_4H_{10}$ would be seven years. Subsidizing the capital cost of the digester would reduce the payback period to 1.5 years if only maintenance was considered.

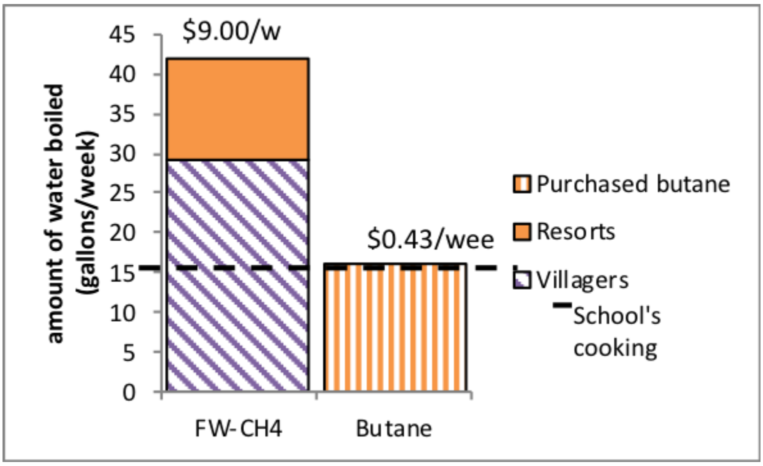



Figure 2: Methane from food waste compared to purchased butane needed to boil water
Note: The school needs sixteen gallons of boiled water/week to meet cooking needs. The food waste collected from five villagers and one resort produces and exceeds the amount of $CH_4$ that is needed to meet school's demand. The cost of purchasing $C_4H_{10}$ is $0.43/week and the cost of the AD prototype for one year is $9/week.
AD = anaerobic digester, FW = food waste, $CH_4$ = methane and $C_4H_{10}$ = butane
*Source: Hobbs, Morton, Barclay, and Landis*

The surplus $CH_4$ could be used as a fuel for cooking in community members' homes and resorts. It was calculated that 231 gallons of boiled water is needed to meet the entire community's needs for cooking three meals per day over a course of one week. If food waste were collected from every home and four resorts, methane obtained from AD would exceed needs for household cooking by 60 percent. This excess $CH_4$ from food waste could be used to meet the cooking demands of three resorts weekly and offset 18 percent of the needs for an additional resort per week.

### *Impacts to the Environment*

Burying food waste has the highest GWP at 3,029 metric tons of $CO_2$ equivalent emissions compared to AD (Figure 3). WARM was used to estimate GHG emissions from burying while $CO_2$ emissions from burning food waste were not counted because it is considered to be biogenic (FAO 2013; EPA 2016b). AD results in negative GWP because $CH_4$ is recovered instead of being emitted into the atmosphere. Since upstream emissions (e.g. embodied carbon) as well as construction and operation of infrastructure are not included in any of the scenarios, only $CH_4$ generation from AD for energy use is considered.

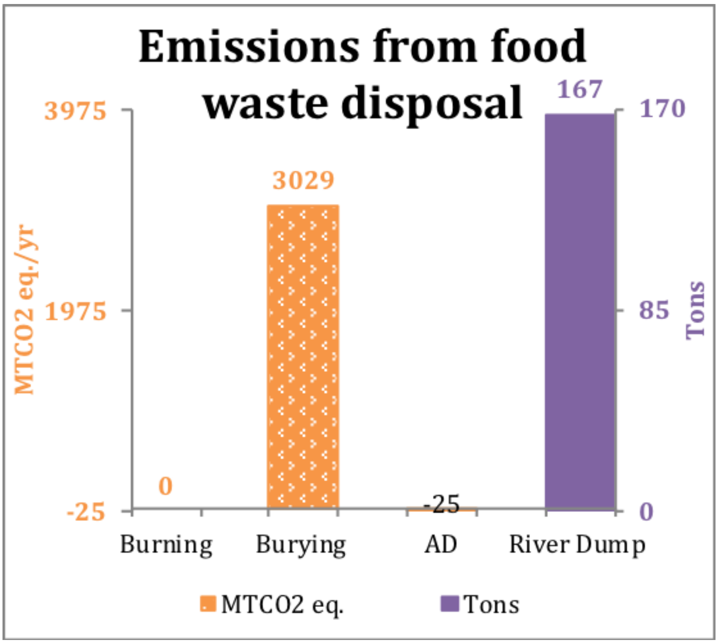



Figure 3: Food waste emissions [in terms of $CO_2$ eq (on the left) and tons trash (on the right)] from Sittee River for one year. Note: River Dump on the x-axis represents the tons of food waste disposed of directly into rivers. AD = anaerobic digestion. $CO_2$ emissions from Burying and AD were calculated using WARM. $CO_2$ emissions for burning are biogenic.
*Source: Hobbs, Morton, Barclay, and Landis*

Burning of food waste in uncontrolled burn barrels results in pollutants such as carbon monoxide and small particulate matter (PM) that are hazardous to human health and impact the environment (Greenberg et al. 1984). These emissions were not included in this study because of the complexity of accurately modeling human health impacts, but it should be noted that they do cause important air quality impacts. The WARM model and the Food and Agriculture Organization (FAO) of the United Nations consider combustion of food waste during the agriculture production phase to be negligible since the $CO_2$ emitted is biogenic (FAO 2013; EPA 2016b).

Since there are no tools unique to Sittee River's ecosystem to assess water emissions, the amount of food waste dumped in the river was measured in tons indicating the quantity of waste directly dumped into water bodies (Figure 3). Increased amounts of food waste to the river increases biochemical oxygen demand and disrupt aquatic ecosystems (Chen 2016). Thus there are likely important water quality impacts to consider from this method of disposal.

The results from WARM give insight on decision-making. For example, switching from burying all food waste to AD results in 1032 percent decrease in GWP. Using AD to manage food waste results in significant GWP reduction compared to burning and burying. However, air quality and water quality are likely important factors to villagers health and quality of life, and it will be important to further understand the impacts of PM emissions and any impacts to drinking water quality.

### *Interview Results*

The survey indicated that 41 percent of the respondents worked in the home followed by 23 percent that hold common labor jobs such as construction or household repairs (Table 6). There were 44 percent of respondents that obtained a high school education. The demographics of the interviewed participants' age distribution, high school education, and occupation distribution reflect the observed demographic characteristics of Sittee River Village. Although only eighteen people were interviewed, their ages ranging from twenty-three to seventy-three, their differences in education help to represent the larger population. Furthermore, there was an equal response between genders, nine male and nine female. When describing their standard of living, 12 percent identified as poor while the rest ranged from fair to comfortable. The results of the June 22–29, 2015 survey (Table 6) represent 7.8 percent of the population over the age of 18.

Table 6: June 2015 Interview Results

| Survey Question (N = number of responses) | Response options | # |
|---|---|---|
| **Gender (N = 18)** | Male | 9 |
| | Female | 9 |
| **Age (N = 18)** | 18–25 | 2 |
| | 26–40 | 7 |
| | 41–60 | 6 |
| | >60 | 3 |
| **Years in Sittee River (N = 18)** | >10 | 6 |
| | Entire life | 12 |
| **High School Education (N = 16)** | Yes | 7 |
| | No | 9 |
| **Occupation (N = 17)** | Common Household Labor | 4 |
| | Housewife | 7 |
| | Tourism | 2 |
| | Engineer | 1 |
| | Farmer | 1 |
| | Unemployed | 2 |
| **Access to Electricity (N = 18)** | Yes | 18 |
| | No | 0 |
| **Type of Fuel Used (N = 16)** | Butane | 12 |
| | Other (Kerosene, Propane) | 2 |
| | Multiple | 2 |
| **Standard of Living (N = 17)** | Comfortable | 4 |
| | Good | 8 |
| | Fair | 3 |
| | Poor | 2 |
| **Sittee River Is Sustainable (N = 16)** | Yes | 12 |
| | No | 4 |
| **Trash Disposal (N = 18)** | Burn | 13 |
| | Drive to Landfill | 1 |
| | Burn and Bury | 4 |
| **Trash Disposal Is Harmful to the Environment (N = 18)** | Yes | 10 |
| | No | 7 |
| | Not Sure | 1 |
| **Trash Collection Service Available (N = 18)** | Yes | 0 |
| | No | 18 |

Note: The total number of interview respondents was eighteen. The “n” after each question represents the number of responses to that question; some questions were not answered. In the far right column, # indicates the number of respondents selecting each option.

*Source: Hobbs, Morton, Barclay, and Landis*

Interviewees were also asked about their electricity and fuel consumption. All of the interviewees had access to electricity, although a respondent stated that there is a small percentage of the villagers without electricity. The number of respondents that use $C_4H_{10}$ as their cooking fuel was 75 percent. When asked what being sustainable means to them, the interviewees used words such as "to sustain," "to keep going," and "to have enough to live." Sittee River is considered a sustainable village by 75 percent of respondents. There were 56 percent of respondents who believed that burning and burying their trash is harmful to the environment while 39 percent said it was not and 6 percent was unsure.

There is no trash collection service in Sittee River. Residents burn and/or bury their trash; 94 percent of respondents reported doing one or both. There were 72 percent of respondents that burn their trash and 22 percent both bury and burn their trash. One person responded that they are able to transport their trash to the landfill by car. The closest unsanctioned landfill to Sittee River is in the neighboring village of Hopkins; it takes approximately fifteen minutes to drive there. The next closest sanctioned landfill is Six Mile junction (approximately fifty miles) drive away located at the Six Mile junction. Therefore, it is most convenient for community members to burn their trash at home, especially if they do not have a car. In addition, according observations about the village, most villagers do not own a car. The research team was able to visit the Six Mile junction landfill and found that trash is burned there as well. Therefore, Sittee River residents have no choice but to manage their waste unless they have their own transportation to the landfill and deem transporting garbage as beneficial compared to burning, burying and/or dumping in river.

A second round of interviews was conducted from August 1–15, 2016 to understand the community's perception of climate change and environmental impacts. The interview results show that two out of the five community members interviewed have noticed climate change effects such as increased temperatures, less rain, and change in fruit development. Eighty percent believed that burning trash was harmful to their health and the environment. One woman explained that "we know [burning the trash] goes in the air somewhere, but we don't know where and we don't smell it here. There is nothing else we can do but burn the trash."

Despite recognizing that burning trash was harmful, residents expressed concern that there were no other options and that they were doing the best that they could. Interviewees made comments such as "[burning trash] is bad for the environment, but what can I do? Instead of throwing it in the river or the bushes we burn it. We are used to the pollution here so it is nothing to us." Another resident said, "We burn our trash in the backyard away from the house so it doesn't hurt us." On the other hand, one comment shows a possible misunderstanding about the impacts of air quality on human health. When asked, "Do you think burning trash is harmful to the environment," the interviewee responded, "Sittee River has a lot of trees for oxygen so we don't have to worry about it."

Using the responses from both surveys, 61 percent of the respondents recognize the severity of burning their trash. However, the other members believe their village is sustainable because it has a lot of trees and greenery, but are not aware of how burning their trash can affect their personal health and their environment. Even so, those that do understand the harmful effects of burning and burying their trash have no other choice but to do so due to a lack of waste management services in the village.

Although none of the interviewees reported dumping waste in river, the research team observed villagers doing so after category 1 Hurricane Earle passed through Belize in August 2016. Many of the villagers saw it as an opportunity to get rid of waste by dumping trash in the river since the water was moving faster than usual and quickly drained into the ocean.

During the research team's meetings with the village council, the council was very enthusiastic about implementing an anaerobic digester. Most of their enthusiasm went toward the opportunity for economic development including selling the biogas to community members, creating jobs within the community, and selling the used food waste as fertilizer. The council was most worried that the digester would create a bad smell in the village, but they are interested in seeing a working prototype to know that digester will not smell. More interviews need to be conducted with the primary school teachers and personnel who would be in charge of cooking the food to understand their concerns of using biogas instead of $C_4H_{10}$.

### *Belize Solid Waste Management Authority*

The Belize Solid Waste Management Authority has developed a Solid Waste Master Plan for Emerging Tourism Areas. This plan is scheduled for implementation in the next ten years. The plan describes the separation of organic waste as an important part of an integrated waste management system. The plan also sites research supporting that organic waste is responsible for $CH_4$ emissions in landfills, therefore suggesting that organic waste would be better disposed of in compost or used as a source of renewable energy. The plan considers AD as a solution to managing organic waste, however the Authority will not implement the technology until their waste management plan is fully established (HYDEA SpA 2016).

The plan notes that rural villages, such as Sittee River, are accustomed to separating their organic waste for compost. This gives Sittee River an advantage in developing a waste management plan that incorporates AD. Implementing a digester in Sittee River can serve as an example to the Belize Solid Waste Management Authority of what can be achieved with AD and provide best practices for future waste management system implementation throughout Belize.

### *Sustainability of Food Waste Management Options for Sittee River*

Sustainability of food waste management strategies was assessed using several metrics in each of the three pillars of sustainability: social, economic, and environmental. Figure 4 shows normalized results to compare the different options (burn, bury, river dump, AD) for managing food waste in Sittee River based on the three pillars. Environmental sustainability is represented by GHG emissions and tons of waste dumped directly into water bodies. Economic sustainability is represented by the cost of using $CH_4$ from food or to purchase $C_4H_{10}$. Note that the cost of using $CH_4$ does not include capital and maintenance costs associated with AD. Social sustainability is represented by social acceptance, determined by applying a Likert scale to the results of the interviews and survey.

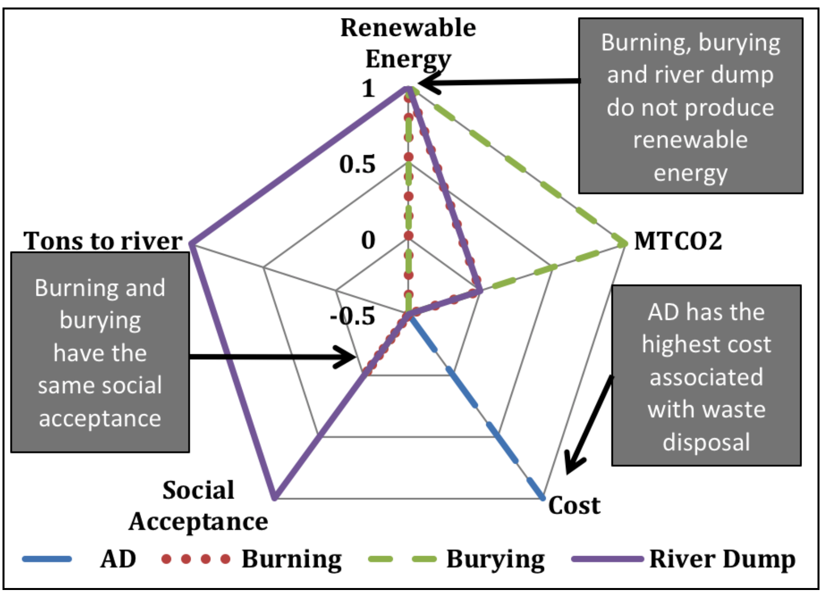



Figure 4: Normalized sustainability footprint of AD, burying, river dump, and burning. AD = anaerobic digestion
*Source: Hobbs, Morton, Barclay, and Landis*

AD, indeed, has the smallest sustainability footprint compared to current waste management techniques (Figure 4). AD has the most social acceptance and end of life processes does not result in GHG compared to burning, burying and river dump since $CH_4$ is produced as a renewable energy source. Although there are costs associated with using AD, overall the sustainability footprint is less. Unlike AD, burning, burying, and river dump do not produce a renewable energy source; therefore $C_4H_{10}$ must be purchased for cooking if these waste management techniques are used. Burning has the next smallest sustainability footprint in terms of environment, mainly due to the fact that emitted GHG are lower than burying and there is no kg of waste to the river unlike river dump. Although burying and burning have very different environmental affects, both have the same social acceptance. If other environmental impacts were able to be included (e.g. PM emissions which would likely increase the footprint of burning waste, water quality degradation which would likely increase the footprint of dumping waste into rivers), then AD may very well show to be an even better alternative food waste management strategy.

## Conclusion

The results and analysis of this sustainability study reveal the interaction of economics, energy, greenhouse gas emissions, and community engagement in the application of waste-to-energy systems to a rural community in Belize. Findings from the waste audits reveal that there are cost tradeoffs between using $CH_4$ gas produced from food waste and $C_4H_{10}$ gas when used for food preparation. However, in terms of social and environmental factors, using an AD for waste management can address related challenges in rural communities. One such challenge that the surveys reveal is the need for heightened community awareness of the harmful effects of burning, burying, and dumping trash in river and alternative waste management systems. Thus, community engagement through education and decision-making in planning, design, and installation processes will lead to a more effective technical waste management system, while building trust with the community.

Community leaders revealed that many young community members end up leaving the village to live in more developed areas where there are more job opportunities other than the saturated tourism industry in Sittee River. Incorporating AD as new waste management technique may prove to reduce GHG emissions while providing fuel for cooking and more jobs for the new generation of employees allowing Sittee River Village to grow and thrive.

While this work addresses the community engagement process as a bridge between sustainability factors and the technical AD system, further research is needed to show how risks associated with AD affect the planning and design of the system. This work sets the basis for deeper exploration of community engagement by incorporating user experiences and perspectives. Once the AD project is piloted and fully implemented, future studies can show how the community engagement process works to enhance or hinder project outcomes such as cost-effectiveness, schedule, and project quality. This work will serve to support the interactive process between the influence of sustainability factors and the subsequent influence of community engagement on the AD system.

Insights from this research can be used to inform sustainability frameworks for similar waste-to-energy cases. For instance, this work is particularly relevant since the Belize Solid Waste Management Authority is considering AD in its future plans for waste management. The approach, results, and analysis from this work can serve as an example that informs plans for other small rural developing communities.

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