CHAPTER 3
METHODOLOGY

3.1 Study-Site Description

Charassaeng Limited Partnership was established in 2003 in Ratchaburi Province with a production capacity of around 40 tonnes of dry mango per year associated with their mango orchards of around 29 ha in nearby areas. Nowadays, Charassaeng factory processes 150 to 200 tonnes of ripe mangoes per year which comes from three sources as follows: (1) from their own orchard, about 80 tonne (40% capacity), (2) from other mango orchards located around the factory, about 20 tonnes (10% capacity), and (3) from buying extracted pulps from the peeling mango factory, about 100 tonnes (50% capacity). Figure 3.1-3.4 presented the factory, orchard, and mango processing in the factory. The schedule of annual operation of the dry mango processing factory studied is detailed in Section 2.1.1.1.

Figure 3.1 Charassaeng'sfactory

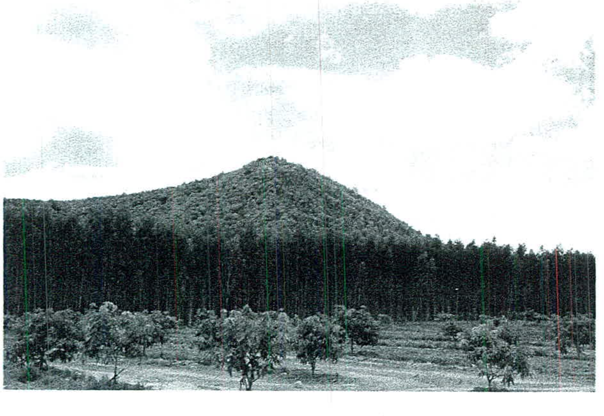

Figure 3.2 Charassaeng's mango orchard

Figure 3.3 Processing areas

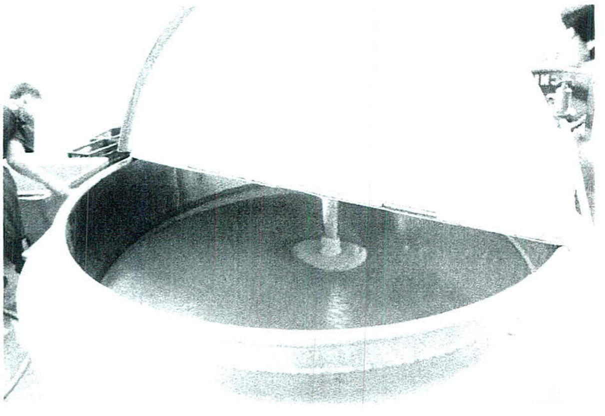

Figure 3.4 Simmer process

3.2 Description of BAU and Alternative Scenarios: Biogas System

In this study, GHG emissions from the open dumping of mango waste (BAU scenario) and the comparative potential GHG performance and cost-benefit associated with an alternative process in which mango peel waste is used for biogas production (alternative scenario) are assessed. In the alternative scenario where mango peel waste are used as substrate for biogas production, potential GHG and cost benefits associated with the substitution of LPG in the factory by biogas would be assessed as compared to the BAU. As part of this assessment, the substitution of chemical fertilizers used by the factory in the BAU to grow mango trees by some amount of solid digestate produced along with biogas from the biogas system would also be included. An illustration of the BAU and alternative scenarios are provided in Figure 3.5.

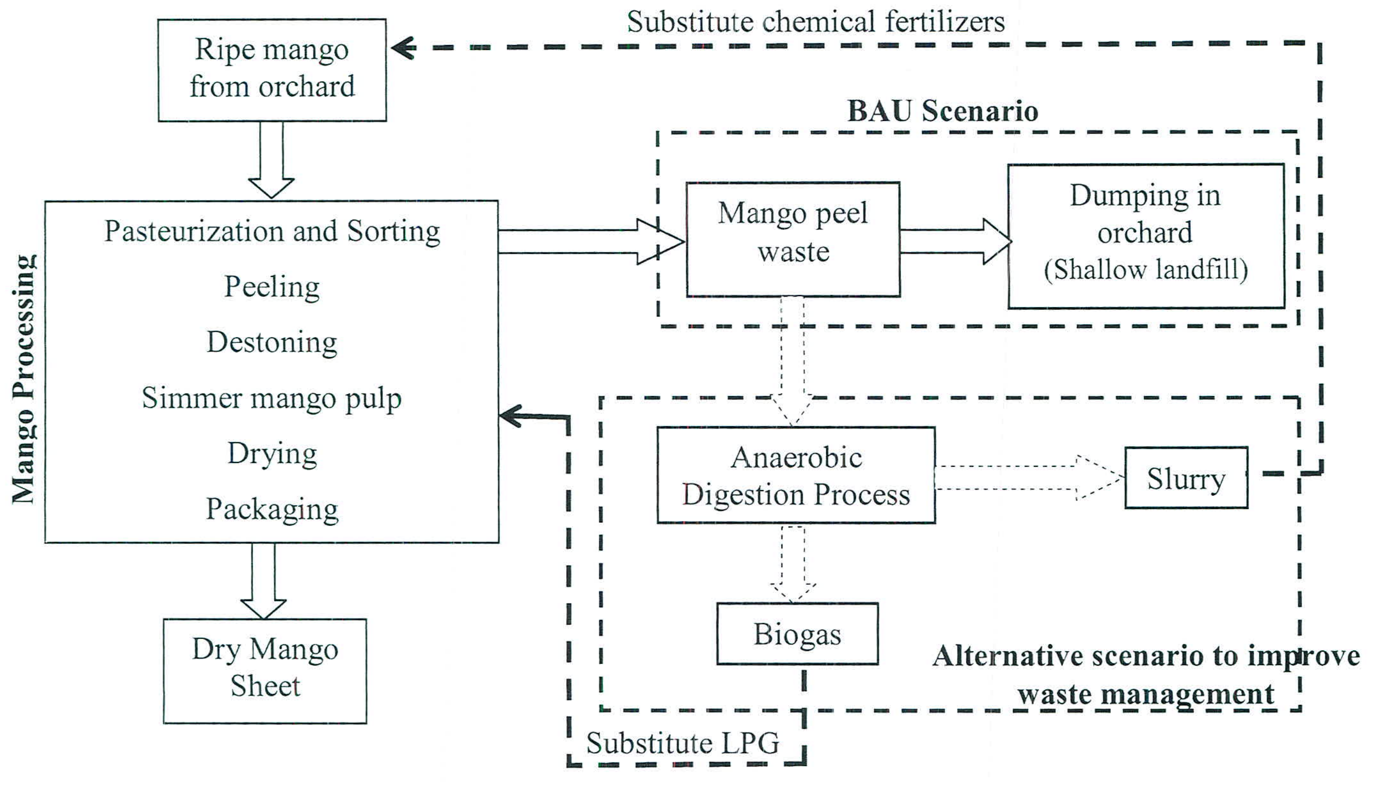

Figure 3.5 Mango waste management in business as usual (BAU) scenario and alternative scenario

3.3 Mango Waste Production

To evaluate GHG performance from conventional waste disposal, the amount of waste generated by the factory need to be determined. Since solid wastes from mango processing mainly include mango peels and mango seeds, only mango peel would be evaluated in this study because of its potential for biogas production. The amount of mango peel waste generated could be determined from the fraction of mango peel per fresh (ripe) fruit weight. Based on published information on Thai mangoes as provided in Section 2.1.2, the fraction of mango peel waste was considered to be 16.5% of the total amount of fresh mango produced (Nagle *et al.*, 2011; Kittiphoom, 2011).

3.4 GHG Emissions Assessment from Open Dumping of Mango Peel Waste

In the BAU scenario, the factory discards mango wastes generated during the processing of dry mango in a nearby mango orchard. Such disposal is considered as open dumping and falls under the category of a shallow landfill. The GHG emissions (i.e. CH_4 emissions) associated with such a waste management system is determined based on the IPCC emission guidelines (1995) and calculated as shown in Equation 4. Details of the factors used to make the assessment, are shown in Table 3.1.

The determination of CH_4 emissions from open dumping of mango peel waste is shown in Equation 4:

$$Methane\ emissions\left(\frac{Gg}{yr}\right) = \left(MPW * MCF * DOC * DOC_F * F * \frac{16}{12} - R\right) * (1 - OX)$$

Equation (4)

where: MPW = total mango peel waste disposed in mango field (Gg/yr)

MCF = methane correction factor (fraction)

DOC = degradable organic carbon (fraction)

DOC_F = fraction DOC dissimilated (default is 0.77)

F = fraction of CH_4 in landfill gas (default is 0.5)

R = recovered CH_4 (Gg/yr)

OX = oxidation factor (fraction - default is 0)

Table 3.1 Environmental impact factors based on IPCC Guidelinesfor shallow landfills (open dumping)

Factors	**Value**
MCF = methane correction factor, unmanaged-shallow (<5m waste)	0.4
DOC = degradable organic carbon (fraction)-food waste	0.15
DOC_F = fraction DOC dissimilated (default is 0.77)	0.77
F = fraction of CH_4 in landfill gas (default is 0.5)	0.5
R = recovered CH_4 (Gg/yr)	0.0
OX = oxidation factor (fraction - default is 0)	0.0

MPW is calculated based on the amount of fresh mango processed by the factory over the mango season (120 days), and the overall mango peel waste generated from such processing activity is 33,600 kg.

3.5 GHG Performance Assessment of the Alternative Biogas System

3.5.1 Biogas Generation

Biogas is produced from the process of anaerobic digestion of recycling mango peel as the substrate of the system.The biogas produced from mango processing waste was reported by Sumithra and Nand (1989) has an average 58% methane content and biogas yield of 0.36 m^3 kg^{-1}VS. For such CH_4 content, biogas has a net heat content of 37.74 MJ/m^3.

Characteristics of the substrate may affect the performance and stability of microbial activities inthe AD system. A change in the input of slurry may result in a temporary reduction in gas production (Persson *et al.*, 1979). Quantitative information about the composition of the input substrate is important to operate the AD system efficiently and avoid malfunctioning. The amount of mango peel generated from the mango factory investigated in this research can be determined based on total mango production and fraction of mango peel waste generated as reported in Section 3.3. Characteristics of mango peel composition based on published information (see Table 2.2) are summarized in Table 3.2

Table 3.2 Average compositional analysis of mango peel

Properties	**Unit**	**Avg.Value**
Moisture content (MC)	% wet basis	72.99±1.46[a]
Ash content (AC)	wt.%db	4.22±0.73[a]
Volatile solid (VS)	wt.%db	71.53±1.29[a]
Fixed carbon (FC)	wt.%db	24.25±0.63[a]

Source: [a]Nagle et al., 2011

Only some fraction of volatile solids (VS) in mango peels can be converted into gas. Some VS still remained in the system as not all VS can be converted in the limited time available for microbial digestion (retention time) (Persson *et al.*, 1979). The remaining VS and some unconverted materials such ash and fixed carbon become solid digestate.

3.5.2 GHG Performance of Biogas as Substitute for LPG

In this study, due to time limitations, the GHG emissions associated with the production of the raw material, construction, maintenance, and demolition of biogas systems, as well as parts and infrastructure used for gas distribution were not included. Only the emissions associated with the production (energy input and leakage) and use of biogas (for cooking mango) were included in the study. GHG emissions resulting from biogas production, for energy input i.e. electricity, was obtained from Thailand Greenhouse Gas Management Organization (TGO, 2013) and leakages from Berlund (2006). Those associated with biogas use as cooking fuel were obtained from a report by Smith *et al.* (2000) and Afrane and Ntiamoah (2011). CH_4 can be released to the atmosphere through losses from the biogas systems. The losses can be caused by leakage, deficient technology, or excess production of biogas when the energy demand is low (Afrane and Ntiamoah, 2011). The percentage losses vary from system to system. Berlund (2006) reports methane losses of 1% of the biogas yield when it is used for the generation of heat or electricity. A CH_4 loss of 1% has been assumed in this study. A summary of relevant GHG emission data is given in Table 3.3. The energy input in the system from applied electricity cause CO_2 emissions in electricity generation process. Based on TGO (2013) information, the baseline emission factor of the Thailand's national electricity system in 2011 is 0.55 kgCO_2/ kWh. The biogas system in this study was assumed to consume electricity to operate the shredder machine and the digester's agitator in an amount equal to 960 kWh (shredder machine 90 kWh per month and agitator 150 kWh per month) over the whole mango season (120 days).

Table 3.3 Inventory data for the GHG emissions of biogas (kg flow/MJ)

Output	Biogas as cooking fuel	Biogas Production	Total score
*Data from literature sources**			
Carbon dioxide	0.147	9.8E-03**	0.287
Methane	1.02E-04	1.61E-05	1.18E-04

Note: kg flow/MJ = kilograms of flow per megajoule
** Source: Berlund (2006); Smith et al., (2000); Afrane and Ntiamoah (2011); TGO (2013)*
*** Energy input from electricity over 120 days*

In Thailand, LPG is extensively used for cooking fuel in households or in small food processing factories.For this factory, in the BAU scenario, LPG is used as a source of energy in the form of heat to cook mango as part of the factory's mango processing operations. The biogas produced using mango peel waste would be used to substitute for LPG. The system for consists of LPG production in the refinery and use for cooking fuel. The emissions for upstream such exploration, extraction, and transportation of crude oil are excluded in this study. Only production of LPG at the refinery and use as cooking fuel are included. The data was taken from the Swiss Ecoinvent LCA database (Afrane and Ntiamoah, 2011). The emissions resulting from burning of LPG as cooking fuel were taken from Jungbluth (1997) studied. Refinery plant equipments for all the system studied were excluded from this study (Afrane and Ntiamoah, 2011). Summaries emissions data for GHG emission of LPG are illustrated in Table 3.4.

Table 3.4 Inventory data for the GHG emissions of LPG (kg flow/MJ)

Output	LPG as cooking fuel	LPG Production	Total score
*Data from Swiss Ecoinvent and literature sources**			
Carbon dioxide	0.12	0	0.12
Nitrous oxide	0	4.78E-08	4.78E-08
Methane	1.91E-06	6.24E-07	2.53E-06

Note: kg flow/MJ = kilograms of flow per megajoule;
** Source: Jungbluth (1997), Afrane and Ntiamoah (2011)*

3.5.3 Assessment of Amount of Slurry Digestate Generated from Mango Peel Waste

Digestate is the material left over after digestion. The amount of digestate could be determined from relative solids reduction expressed in percent of initial amount of VS. From the studies of Bouallagui *et al.* (2005) and Lin *et al.* (2011) as referred to in Section 2.2.4 results of percent VS removal from fruit and vegetable wastes digested in anaerobic conditions are in the range 70 to 88%. An average value from this range was used in this study, i.e. 77% VS removal for mango peel waste. The mass balance calculations between influent and effluent of mango peel waste for the AD system of this study are given in Table 3.5.

The input section is the mango peel components that Nagle *et al.* (2011) had studied as presented in Table 3.2 but grouped in two major compositions: biodegradable section (VS) and non-biodegradable section (ash+fixed carbon). After the digestion, some VS would be converted to biogas (77% VS removal for this study). The remaining fraction could be considerable such solid digestate. The reduced VS in output side corresponds to 77% of 71.53 kg VS that is about 55% of total solid converted to biogas and almost 45% TS produced as solid digestate, on a daily basis.

Table 3.5 Mass balance between the input and output substrate

Item	**% by weight of TS**
Input	
Ash + Fixed carbon = Non-degradable	28.47
Total volatile solid (VS)	71.53
Output	
Volatile solid reduction	55.08
Digestate (remained VS + ash + fixed carbon)	44.92

3.5.4 GHG Performance of Digestate Slurry as Substitute to Chemical Fertilizer

The assessment of the GHG performance of the slurry digestate produced from the biogas system of this study consists in assessing the GHG emissions from fertilizer production that are avoided through the use of digestate slurry in the mango plantation.

Due to a lack of information regarding the nutrient content of the slurry digestate that produced from the fermentation of mango peel waste, N, P, K values of the mango peel were used as substitute. It was assumed that the N, P, K content of the slurry digestate was same as that of mango peel. From the elemental compositions of mango peel waste as mentioned in Section 2.1.2, N, P, K values are provided in Table 3.6.

Table 3.6 N, P, K nutrients contented in mango peel

	N	**K**	**P**
	wt.%db	mg kg^{-1}	wt.%db
Mango peel*	0.91	13,400	-

** Source: Nagle et al., 2011*

The estimation of avoided GHG emissions per tonne of solid digestate substituting chemical fertilizer for each nutrient element (N, P, K) are reported in Table 3.7.

Table 3.7 Digestate nutrient concentrations, kg nutrient/tonne fresh weight of solid digestate

Nutrient element	**$kgCO_{2eq}$/kg element***	**Nutrient content in solid digestate kg/tonne of solid digestate**	**Avoided emissions $kgCO_{2eq}$/tonne of solid digestate**
N	5.29	9.1	-48.1
P	0.52	-	-
K	0.38	13.4	-1.7
Total			-49.8

** Emissions corresponding to the manufacturing of chemical fertilizer*

According to information from the dry mango factory investigated in this research, fertilizers are to be applied after the trees have blossomed, so that there are enough nutrients to produce mango fruits. Although the factories did not have specific record of fertilizer being applied in the mango field, a general summary of fertilizers applied per plant in Thailand was retrieved from the Department of Agriculture (DOA) as presented in Table 3.8.

Table 3.8 Fertilizer requirements for mango plantations in Thailand

Period	Fertilizer formula			
	15-15-15	30-0-0	8-24-24	15-7-18
	kg/plant/year	kg/plant/year	kg/plant/year	kg/plant/year
Round 1: Blossom Enhancer Mix	2	10	4	-
Round 2: Flower to Fruit Converter Mix	2	-	-	-
Round 3: Fruit Growth Booster Mix	-	-	-	2
Total	4	10	4	2

Source: http://it.doa.go.th/vichakan/news.php?newsid=37

This information was used by default to calculate the nutrient requirements of mango plantations. An illustration of the process followed to perform this assessment is given using the fertilizer of formula 15-7-18 as an example. Such a formula means that 15% of the weight of the fertilizer is nitrogen (N), 7% is phosphorous (P) as P_2O_5 equivalent and 18% is potassium (K) as K_2O equivalent. To determine the actual amount of each nutrient equivalent in the fertilizer, multiply the weight 100 kilograms by the percentage of that nutrient equivalent in decimal form. So to determine the actual nitrogen content in a 100 kg of 15-7-18 fertilizer; = 15 kg of actual N material, 7 kg of P_2O_5, and 18 kg of K_2O. To convert P_2O_5 to P, multiply P_2O_5 by 0.44 and multiply K_2O by 0.83 to convert to K.

Based on the above calculation process, the nutrients availability of, such as nitrogen (N), phosphorous (P), and potassium (K) for mango plantation in Thailand were determined as reported in Table 3.9.

Table 3.9 Nutrient requirements for mango plantations (kg/plant/year)

	15-15-15 (kg)	**30-0-0 (kg)**	**8-24-24 (kg)**	**15-7-18 (kg)**	**Total (kg)**
N	0.6	3.0	0.32	0.3	**4.22**
P as P_2O_5	0.6	0	0.96	0.14	1.7
K as K_2O	0.6	0	0.96	0.36	1.92
Convert to P	-	-	-	-	**0.75**
Convert to K	-	-	-	-	**1.59**

The results in Table 3.9 show that the total nitrogen (N) requirement of mango is 4.22 kg, phosphorous (P) is 0.75 kg, and potassium (K) is 1.59 kg per plant per year. This information was used in combination with the data reported in Table 3.8 to assess the GHG benefits resulting from the substitution of chemical fertilizer by slurry.

3.6 Financial Assessment of the Biogas System

Financial assessment for an item is the sum of all expenditures associated with the item during its entire service lifetime. For biogas systems, these costs were covered for capital costs, operating costs, equipment costs, and maintenance and repair costs over a chosen period of 15 years.

3.6.1 Data Collection for Financial Assessment

The market prices of the various components were obtained from direct and indirect sources. The cost factors of the major process are listed in Table 3.10.

Table 3.10 Cost categories for biogas production used mango peel as substrate

Production cost factors	Items	Data sources
Capital	Slurry preparation area, Digester tank, Gas storage, Effluent sludge storage	Literature or reports
Operating	Electricity, Water, Additive chemical, Labor and overhead	Literature or reports
Equipment	Shredded machine, Agitator, Pumps, Control valve, Pressure gauge, Pipelines	Market price references and quotations of equipment

Source: http://www.fluid-biogas.com

3.6.2 Costs of Biogas Plants

Considerations of biogas plant construction and operation costs are necessary for overall financial assessment and require gathering information about financial expenditures. Biogas was considered as renewable energy, which can substitute for LPG (26 THB/kg - EPPO, 2013) used in the production process of dry mango. This aspect was considered for cost-benefit calculations associated with such energy substitution.

Table 3.11 Total costs of biogas plants

Volume of digesters (m^3)	Overall cost of biogas plant (THB)*
15	396,000
25	495,000
50	705,000

** The price does not include transportation and taxes.*
Source: http://www.fluid-biogas.com

The overall price for a biogas plant based on size of digester is given in Table 3.11. For rough calculation of typical cost of a simple biogas plant, the following value can be used: overall cost of the plant excluding land cost is approximately 15,000 THB/m^3 of digester volume. Around 30-40% of the overall cost is digester cost (see; www.fluid-biogas.com).

Cost of Digester

To estimate the cost of the digester to be implemented for the mango factory investigated in this research, the type and volumetric capacity of the reactor need to be identified. As mentioned in Section 2.2.2, the digester to be selected for the mango factory was assumed to be a one-stage semi-continuous feed system (CSTR). Steady state operation and well-mixed condition are the assumptions of this reactor in this study. Calculations to assess the digester's size require information about substrate properties and design criteria (functional requirements). The average composition analysis of mango peel waste was presented in Table 3.2 and the functional requirement of the AD process detailed in Section 2.2.1. Based on this information, the main functional requirements of the biogas system selected for the mango factory investigated in this research work are reported in Table 3.12.

Table 3.12 Functional requirement of the AD process

Functional requirement	**Unit**	**Avg.Value**
Retention time	days	15[a]
Solid concentration	%TS	6[b]
Organic Loading Rate (OLR)	kgVS m^{-3}	1.9[c]

Source: [a]Somayaji, 1992;[b]Sumithra and Nand, 1989; [c] from calculation

The assessment of the digester size is based on Persson *et al.* (1979), and is detailed below:

Calculation of Digester Size:

Based on the assumption that 1,700 kg per day of ripe mango is processed:

A. Calculate weight and volume of mango peel to be handled.

Weight = 0.165*1,700

= 280.0 kg/day

B. Calculate dry matter to be handled (TS components of mango peel from Table 3.3)

(Ash+fixed carbon = 28.47% of mango peel weight)

Dry matter (TS) = 0.2847*280.0

= 79.72 kg.

C. Calculate weight and volume of slurry to be moved into the digester each day.

Solid concentration of slurry (Table 3.13): 6%TS

Total volume: mango peel + dilution water

Total weight of slurry = dry matter (TS)/0.06

= 79.72/0.06

= 1,328.67 kg.

Total volume of slurry = total weight/density of mango peel

= $1{,}328.67/675^{*}\ m^3$ (* see Section 2.1.2)

= 1.97 m^3

D. Calculate the volume of digester chamber for specific retention time

Retention time in this study: 15 days (see Section 2.2.1)

Chamber volume: daily slurry production x retention time

= 1.97 x 15

= 29.55 m^3

E. Check daily organic loading rate (OLR)

Volatile solid as mentioned in Table 3.3 equal to 71.53% of total solid (TS)

= 0.7153 x 79.90

= 57.15 kg VS

Daily organic loading rate: daily total VS/volume of digester chamber

OLR = 57.15/29.55

= 1.93 kg VS $m^{-3}d^{-1}$

F. Total volume of digester chamber

As mentioned in Section 2.2.5: Total volume of digester

$V_{req} = V_{gas} + V_{dig}$ ....Equation (1)

$V_{dig} = 29.55\ m^3$ ....Equation (3)

V_{gas} = free board for temporary storage of produced gas

= 10% of V_{dig} ....Equation (2)

= 0.1 x 29.55

= 2.95 m^3

V_{req} = 2.95 + 29.55

= 32.5 m^3

Costs of biogas storage systems

The least expensive and easiest to use storage systems for on-site applications are low-pressure systems and intermediate storage of biogas. The energy, safety, and scrubbing requirements of medium- and high-pressure storage systems make them costly and high-maintenance options for on-farm use (Krich *et al.,* 2005). In this study, a low-pressure storage system is considered and its cost estimated on a percentage basis of the digester's cost.

3.6.3 Operating Costs

For operating and maintenance costs (O&M), estimations are based on the following assumptions:

(1) No extra workers

(2) Water cost 20 THB/m^3 for small industry (PWA, 2013)

(3) Electricity cost 3.5 THB/kWh (PEA, 2012)

Water is used as part of the slurry preparation process to dilute the mango peel waste. In this study, dilution water is around 1.3 m^3 per day. Therefore, monthly water cost is (1.3m^3/d x 30 day x 20 THB/m^3) 780 THB. Electricity is used for the shredder machine (slurry preparation) and the agitator (fermenter). Power for shredder machine was derived based on data from a manufacturer (i.e. Zhengzhou Shuliy Machinery Co., Ltd.) and agitator from a manufacturer (i.e. www.tacmina.com). The power requirement was assessed based on the daily amount of waste generated and the volume of the digester required to process it into biogas. In this study, the power for the shredder machine and the agitator was assumed to be 3 kW and 5 kW respectively. In this assumption, the electricity cost for the shredder machine was assessed to be equal to 315 THB (3 kW x 1 hr/day x 30 day/month x 3.5 THB/kWh) and 525 THB for the agitator (5 kW x 1 hr/day x 30 day/month x 3.5 THB/ kWh). Therefore, the total electricity cost for operating the biogas system was evaluated at 840 THB per month.

3.6.4 Assumptions in Financial Assessment

Escalating Costs

In this study, the costs of LPG and chemical fertilizers were assumed to increase by 3% each year. While the electricity tariff and water tariff for the base year (2013) was 3.5 THB/kWh and 20 THB/m^3 respectively, it was assumed to increase by 1% each year.

Bank Loan and Repayment

In this study, the assumption of a bank loan is 66% of capital investment cost and for periodic payments over 10 years.