CHAPTER 4
RESULTS AND DISCUSSION

4.1 Environmental and Cost Performance Assessment of Mango Peel

4.1.1 Mango Peel Waste Disposal

In the BAU scenario, the daily amounts of mango peel waste generated was estimated based on the amount of ripe mango processed by the mango factory. According to the information from the mango factory investigated (see Section 3.1), about 1,700 kg of ripe mango are processed per day. As mango peel represents about 16.5% of this fresh weight (see Section 3.3), this translates into about 280 kg of fresh mango peel waste generated on a daily basis from mango processing operations.

Since the mango harvest season lasts for approximately 4 months in a year, mango peel waste was generated over 120 days in that season. This means that the total amount of mango peel waste generated by the factory each during the mango harvesting season amounts to 33,600 kg.

The determination of GHG (CH_4) emissions from the 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)

The CH_4 emissions related to open dumping of mango peel waste in nearby areas amounts to 1,035 kgCH_4 per year. Since methane traps 25 times more heat than CO_2, the corresponding global warming potential amounts to 25,875 kgCO_{2eq} per year.

Table 4.1 GHG emissions from mango peel waste open dumping in the BAU scenario

Factors	**Value**
MPW = mango peel waste generate (Gg/yr)	33.6×10^{-3}
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
Methane emissions (kg/yr)	**1,035**
Global Warming Potential impact (GWP) ($kgCO_{2eq}$ /yr)	**25,875**

4.1.2 Mango Peel Utilization as Feedstock for Biogas Production

Products and By-products of AD System

(1) Biogas

For 280 kg of mango peel produced per day, the corresponding composition in TS, AC and VS of the mango peel that could be recycled as substrate to produce biogas is summarized in Table 4.2.

Table 4.2 Mango peel composition

Properties	**Amounts (dry basis) (kg/280 kg of mango peels /day)**
Total Solid (TS)	79.72
Ash Content (AC)	3.36
Volatile Solid (VS)	57.02

Biogas is produced from the conversion of VS. According toTable 4.2, the amount of VS in the substrate is 57.02 kg and the biogas production rate based on Table 2.5 is 0.36 m^3 kg^{-1} VS added. Therefore, the biogas yield is 20.5 m^3 per day or 2,460 m^3 per year (over 120 days of mango season). Information about the amount of biogas produced and approximate characteristics of the biogas from mango peel waste are summarized in Table 4.3.

Table 4.3 Production and characteristics of biogas from mango peel waste

	Amount	LPG equivalent (kg)
Biogas yield (m^3)		
Daily	20.5	**9.8**
Annually	2,460	**1,176**
Calorific value (MJ)		
Daily	449	
Annually	53,880	

The calorific value of the biogas produced from mango peel fermentation can be estimated based on the percentage CH_4 content in biogas (on a cubic meter basis). In this study, based on Sumithra and Nand (1989), it was assumed that the biogas CH_4 content is 58 %. The heating value of biogas produced per day is 449 MJ (21.9 MJ/kg). This is equivalent to 9.8 kg LPG cylinder type (45.8 MJ/kg). The total heating value obtained from biogas amounts to 53,880 MJ which is equivalent to 1,176 kg of LPG. This represents approximately 17% of the factory's requirement in LPG for mango processing over a year (in the BAU scenario, the mango factory requires 6,900 kg/yr of LPG or 316,020 MJ/yr).

(2) Solid Digestate

The amount of solid digestate produced from the biogas system can be estimated based on the methodology detailed in Section 3.5.3. According to data reported in Table 3.6, about 45% by weight of the initial TS entering the biogas process would come out as solid digestate. Since the substrate contains 79.72 kg TS, the daily amount of solid digestate produced would amount to 35.8 kg or around 4,300 kg produced per year (that is over the 120 days of the mango harvesting season). The nutrient content of the solid digestate can be evaluated based on the nutrient content of the mango peel (see data reported in Table 3.7) Since it was assumed due to limitations of data that the nutrient content before and after digestion would be the same, total nitrogen (N) content per tonne of solid digestate is estimated to amount to $9.1 \times 4.3 = 39.1$ kg of N, while, total K content is (13.4 g/kg×4300 kg) 57.6 kg of K. The result from this study indicated that digestate could substitute around 0.2% of chemical fertilizer requirement for mango plantation of this factory (refer to in Table 3.9 and 3.10) based on N-nutrients and 0.8% based on K-nutrients. Total substitution rate is approximately 1% of chemical fertilizers requirement for mango orchard utilization.

Life Cycle GHG Assessment

To assess environmental performance with regard to GHG emissions by shifting away from the BAU scenario of mango peel waste open dumping to its utilization as feedstock for biogas production, three aspects can be considered. The first concerns the GHGs that are emitted from the processes leading to biogas production and also from using biogas as cooking fuel to substitute LPG. The second aspect relates to the avoided GHG emissions associated with the amount of LPG substituted by biogas in the mango factory. These GHG emissions are associated with LPG production and use as cooking fuel. The third aspect relates to avoided emissions from the digestate slurry (co-product generated along with biogas) used to substitute chemical fertilizers in the mango plantations supplying the factory. Main GHG emissions are those associated with the manufacture of chemical fertilizers, particularly N_2O emissions from nitric acid manufacture. In this study, it has been estimated that approximately 1% of the chemical fertilizers used in the BAU scenario can be substituted by solid digestate from the biogas system (see previous section). The global warming potential impacts associated with biogas and the solid digestate are summarized in Table 4.4.

The results indicate that the utilization of biogas to substitute LPG and solid digestate to replace chemical fertilizers would improve the GHG performance of the biogas system (mainly from LPG substitution). It is indeed observed from Table 4.4 that the GHG emissions associated with biogas production amount to 8,607 $kgCO_{2eq}$/yr. and that the substitution of LPG by biogas and chemical fertilizer by solid digestate bring GHG credits amounting to 6,684 kg CO_{2eq}/yr. This brings the total GHG emissions of the biogas system to 1,923 kg CO_{2eq}/yr. As compared to the BAU scenario in which GHG emissions associated with mango peel waste open dumping were estimated to amount to 25,875 $kgCO_{2eq}$/yr, the biogas system appears to be an environmentally friendlier, and therefore, preferred option.

Table 4.4 GHG emissions associated with the biogas system for the mango factory

1	**Total biogas yield per one season crop year**	**(m^3/yr)**	**2,460**
2	Heat content of whole biogas	MJ/yr	53,880
3	GHGs emissions from biogas production	kgCO_2eq/yr	549.68
4	GHG emissions from biogas as cooking fuel	kgCO_2eq/yr	8,057.76
5	**Total GHGs emissions from biogas**	**kgCO_2eq/yr**	**8,607.44**
6	Avoided GHG emissions from LPG production	kgCO_2eq/yr	-1.61
7	Avoided GHG emissions from LPG as cooking fuel	kgCO_2eq/yr	-6,468.17
8	Total avoided GHG emissions from LPG (6+7)	kgCO_2eq/yr	-6,469.78
9	Avoid GHG emissions from chemical fertilizers substitution	kgCO_2eq/yr	-214.14
10	**Total avoided GHGs emissions (8+9)**	**kgCO_2eq/yr**	**-6,683.92**
11	**Total GHG emissions from biogas system**	**kgCO_2eq/yr**	**1,923.52**

Financial Assessment of Biogas System

Basic Components of Biogas System

For financial assessment, information about the basic components of a biogas system is necessary. The dimension and sizing of each component of the biogas system as well as the type of digester are important parameters influencing the installation and operating costs of the entire system. As mentioned in Section 3.6.2.2, the volume of the digester and gas storage bag capacity are 33 m^3 and 20 m^3, respectively.

The total investment cost is comprised of construction costs and installation costs associated with basic components of the biogas system. The determination of the overall cost of the biogas system considered in this study was based on educated assumptions made during a related internship study and information available from manufacturers as explained in Section 3.6.2.1 (see Table 3.12). As shown in Table 4.5, for a digester of capacity of 33 m^3 and an atmospheric pressure gas storage bag of 20 m^3, the total price of the biogas system can roughly be estimated at 560,000 THB (interpolation from data reported in Table 3.12).

Table 4.5 Cost estimation of biogas system based on digester's capacity

Volume of digesters (m^3)	**Overall cost of biogas plant (THB)**
25	495,000
33	**560,000**
50	705,000

According to the available information, the digester's cost would represent approximately 40% of the total cost while the gas storage bag cost would contribute about 10% of the total cost. For operating and maintenance costs (O&M), the costs for water and electricity are 1,620 THB/month. Over the operational period (120 days), O&M costs amount to 6,480 THB. A break-down of the costs are reported in Table 4.6.

Basic components of the biogas system include the digester chamber, slurry preparation facilities, gas storage unit, and effluent storage and utilization. These units were estimated for the investment and installation costs in percentage of 40%, 20%, 20%, and 20% of overall costs of biogas plant respectively. Annual costs consist of operation and maintenance costs and capital cost. Savings are included in the assessment based on the amount of LPG and chemical fertilizers substituted by biogas and solid digestate respectively. Calculations in the financial assessment include a discount at 7% interest rate using the net present value (NPV) to evaluate the future cash amount occurring at the year 15. The lifetime of the biogas system is considered to be 15 years (as mentioned in Chapter 3).

Table 4.6 Break-down cost of biogas system

	Initial cost (THB)	**Annual cost** (THB)**
Investment Cost		
- Digester chamber (33 m^3)	224,000	
- Slurry preparation facilities	112,000	
- Gas storage unit	112,000	
- Effluent storage and utilization	112,000	
Total investment costs	**560,000**	
Operating Costs& Maintenance Costs		6,480
Capital Costs (interest rate 7 %)*		26,133[a]
Total Annual Costs		**45,680**

**Interestrate x total investment cost, ** annual cost only for 1st year*
[a]*From bank loan 66% of total investment cost*

If the NPV is negative, the project should be rejected. If the NPV is positive, the project should be accepted. Furthermore, the internal rate of return (IRR) is used in capital budgeting to measure and compare the profitability of investments (as mentioned in Chapter 3)

The savings from biogas were determined based on the percentage LPG it was assessed to substitute, i.e. 17%. Based on this, it was estimated to be about 1,176 kg of LPG could be replaced by biogas (the price of LPG is 26 THB/kg (base year 2013)). The savings from using solid digestate as organic fertilizer to substitute chemical fertilizers in mango fields was assessed based on the percentage amount it could substitute , i.e. 1%. Therefore, the overall saving over a year was estimated to amount to 14,490 THB (annual cost of chemical fertilizer purchased by the mango factory is 1.5 million THB (base year 2013).

Table 4.7 Summary of expenditures and savings of biogas system for small mango processing factory with escalation factor

Currency Unit (THB)	Lifetime of Plant															
	Y0	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**	**Y6**	**Y7**	**Y8**	**Y9**	**Y10**	**Y11**	**Y12**	**Y13**	**Y14**	**Y15**
Costs																
Investment	560,000															
O&M cost		6,480	6,545	6,610	6,676	6,743	6,811	6,879	6,947	7,017	7,087	7,158	7,230	7,302	7,375	7,449
Total costs		6,480	6,545	6,610	6,676	6,743	6,811	6,879	6,947	7,017	7,087	7,158	7,230	7,302	7,375	7,449
Revenues																
Saving from using biogas (internal use)		30,576 [a]	31,493	32,438	33,411	34,414	35,446	36,509	37,605	38,733	39,895	41,092	42,324	43,594	44,902	46,249
Saving from using digestate (internal use)		14,490 [b]	14,925	15,372	15,834	16,309	16,798	17,302	17,821	18,355	18,906	19,473	20,058	20,659	21,279	21,917
Total savings		45,066	46,418	47,811	49,245	50,722	52,244	53,811	55,425	57,088	58,801	60,565	62,382	64,253	66,181	68,166
Savings after covering O&M costs		38,586	39,873	41,200	42,568	43,979	45,433	46,933	48,478	50,071	51,714	53,407	55,152	56,952	58,806	60,718
Interest (7%)		26,133	23,520	20,907	18,293	15,680	13,067	10,453	7,840	5,227	2,613	-	-	-	-	-
Repayment (10 years loan)		37,333	37,333	37,333	37,333	37,333	37,333	37,333	37,333	37,333	37,333					
Bank loan & Debt Remaining	373,333	336,000	298,667	261,333	224,000	186,667	149,333	112,000	74,667	37,333	0					
Equity	186,667															
Cash flow (Owner)	**-186,667**	**- 24,881**	**- 20,980**	**- 17,040**	**- 13,058**	**- 9,034**	**- 4,967**	**- 854**	**3,305**	**7,511**	**11,767**	**53,407**	**55,152**	**56,952**	**58,806**	**60,718**

NPV	**-123,458**
IRR	**0.9%**

[a] *Base on 17 % substitution of LPG ; LPG price 26 THB/kg;* [b] *Base on 1 % substitution of chemical fertilizer*

Table 4.7 provides the details of the financial assessment made for the biogas system considered for over 15 years. Y0 refers to the construction period. The total investment cost is 560,000 THB. In this amount, 373,333 THB or 2/3 is loaned, while, 1/3 is paid by the owner. From Y1 to Y15, savings from biogas and solid digestate were increased based on a 3% escalation factor, while O&M costs were increased based on a 1% escalation price. The cash flow is presented in the last row and was obtained by subtracting earning before financial activities with interests and repayment. The cash flow statement from year 1 to year 7 presents liabilities. Since year 8, the project generates a profit (3,305 THB) from the process (total savings subtracted with total costs, interest, and repayment). Based on the cash flow statement, the NPV was calculated using equation 5 (see Chapter 3). For this study, the NPV was assessed to be negative meaning the project is not financially viable under the conditions considered. The IRR of this project cash flow was estimated to be 0.9% interest return which is lower than the present interest rate. An investment should only be considered if the IRR exceeds the required return, which was not achieved for this biogas system.

4.2 Overall Discussion

Based on the results of the mango factory investigated, daily biogas production is equal to 20.5 m^3 or 0.073 m^3/kg of mango peel (wet weight basis). This is also equivalent to 9.8 kg LPG cylinder per day which is less than the daily requirement in LPG (19 kg) for mango processing. Utilization of such amount of waste as feedstock for biogas production and its internal recycling as a source of energy for mango processing would enable to substitute 17% of the annual amount of LPG used by the factory for this purpose.Aside from biogas, a total of 4.3 tonnes of solid digestate is also produced which was estimated could enable substituting about 1% of the total annual requirement in chemical fertilizers for the mango plantations supplying the factory.

In terms of GHG performance, the BAU scenario for a small mango processing factory results in global warming potential impact 0.77 kg CO_{2eq} per kg of mango peel waste (33.6 tonnes) or 25.87 tonnes CO_{2eq} per year. Meanwhile, improvements in waste management by produced biogas and solid digestates, the overall GHG emissions associated with these products were considered lower than those associated with open dumping of mango peel waste, amounting to 0.057 kgCO_{2eq} per kg of mango peel or

1.92 tonnes CO_{2eq} per year. A comparison of the results shows an advantage of biogas system to manage the organic waste.

With regard to the financial assessment of the biogas system, the project was found to be not viable under the conditions assessed. It was found that the NPV was negative and the IRR was too low to justify investment in such a biogas system.