International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2016, 6(2), 318-334.

Design of Biogas Production using Wastewater from Industrial Plants: Financial Analysis of Various Feed-in-tariff Remunerations in Thailand

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ABSTRACT

In this study, we provide a sample conceptual design and explanation of existing biogas plants that can be attached to various kinds of plants that release wastewater with suitable amounts of chemical oxygen demand. Financial information was collected and analysed in terms of investment costs, operational costs and historical data of electricity generation from biogas. The results show that in order to promote biogas business in Thailand, the government should provide feed-in-tariff (FiT) remuneration of 5 baht/KWh when contract capacity is 0.02-2 MW. When contract capacity is increased to >2 MW, but <4 MW, the FiT remuneration should be reduced to 3 baht/KWh/MW to ensure profits of the investment. However, when contract capacity is >4 MW, the government need not provide any FiT remuneration.

Keywords: Biogas Power Plants, Feed-in-tariff, Financial Analysis
JEL Classifications: Q28, Q48, L88

1. INTRODUCTION

Treating wastewater is one of the biggest challenges facing numerous industrial plants in Thailand. Every plant must allocate a significant budget to treat wastewater to keep the environment safe and clean. After several economic crises, rising oil prices have resulted in higher operation costs. In response, many small and medium enterprises in Thailand began seeking ways to reduce their costs and increase the value of their byproducts. Hence, using wastewater as an input to produce an alternative source of energy seems attractive for many private investors.

The Ministry of Energy in Thailand supports the action of treating wastewater to generate electricity. The government also supports any small or medium enterprise that wishes to generate electricity from wastewater by providing a soft loan program that offers loans of up to two million baht (USD 0.6 million) per KWh per year. This is part of the government aim to reach 600 MW for electricity generation from biogas technology by 2036 (EPPO, 2015). The government aims to invest in biogas plants up to 10 MW in capacity (DEDE, 2015a). This capacity is within the range that will attract a sufficiently large number of private investors in Thailand with suitable investment costs. An additional objective is to treat wastewater at many industrial plants. Power plants smaller than 10 MW in capacity are defined as "very small power procedure" (VSPP) (Ueasin et al., 2015).

In 2015, the total capacity of electricity generated using biogas technology in Thailand was only 213 MW. Of this amount, 4 MW was produced from the northern region, 65 MW in the northeastern region, 61 MW in the central region, and 83 MW in the southern region (DEDE, 2015b). Plants in Thailand that qualify for the release of wastewater to generate electricity include paper production plants, oil palm mills, cassava plants, concentrated natural rubber plants, alcoholic beverage plants, vegetable oil refineries, and ethanol plants from the production of cassava and molasses. Across the country, there are a total of 1459 plants that are capable of producing 1311 million m^3 of wastewater and can generate 158 MW of electricity per year. 351 of these plants are already producing electricity using wastewater (TGO, 2015).

Another benefit of using wastewater as an input to produce electricity is that the profits are partially tax deductible for 8 years. Further, carbon credits can be sold under the Certified Emission Reduction (CER) program under the Clean Development Mechanism (CDM) of the Kyoto Protocol. Biogas is ranked second in terms of the number of CER projects. The expected average annual volume of CERs is 4,667,460 tCO_2e (51.15%) from 9,123,866 tCO_2e reduction (TGO, 2015).

The Thai government is currently subsidizing the biogas electricity generation business using the feed-in-tariff (FiT) system by paying a supporting price of 3.76 baht/KWh of electricity generation for 20 years (PDP, 2015). The FiT system is the most commonly used policy instrument. It has been implemented in 65 countries and 27 states or provinces around the world. Fixed FiTs in many countries were calculated based on the minimum life cycle cost per unit of energy that provides the net present value (NPV) of zero for private investment (Aidan et al., 2015).

In 2002, twenty countries in Europe applied FiT schemes as the mechanism to support private investors to promote renewable energy generation (Ragwitz et al., 2012). However, FiT schemes in Europe are mostly for wind and photovoltaic plants, but are very rare for biogas plants. Only a few countries in Europe such as Finland and Germany provide FiT premiums for biogas electricity. Couture and Gagnon (2010) studied various FiT remuneration models for electricity generated from renewable energy sources such as market-independent, fixed price models that create greater investment security. These models lead to lower-cost renewable energy deployment than market-dependent models. This is primarily due to lower investment risks and greater predictability of future cash flows.

The FiT amount per KWh supported by the Thai government has been widely discussed. A study funded by Thai research funding in 2014 did not consider FiT for biogas (Pita et al., 2015). A few VSPPs have been shut down due to losses; the losses may be due to several factors such as insufficient raw materials or costs were too expensive. To solve these problems, this study analyses the optimum amount of government remuneration to biogas private investors needed to promote the production of alternative energy and increase wastewater treatment.

The promotion policy of electricity generation using biogas conforms to another government policy that intends to reduce overall greenhouse gas emission by at least 20% by 2030 (INDC, 2015).

2. EXISTING LITERATURE CONCERNING BIOGAS IN THAILAND

In this paper, we consider two aspects of biogas production. First, we provide a sample design of a biogas electricity generation plant. In the second part, we conduct a financial feasibility study of its implementation. Numerous research sources provide a solid foundation of theory and experience for the present research project.

The review of plant desig n begins with Chaiprasert (2011), who studied biogas production from agricultural wastes in Thailand using different types of technology for treating waste water using an up-flow anaerobic sludge blanket, an anaerobic fixed film, a completely stirred tank reactor, an anaerobic baffle reactor, an anaerobic covered lagoon, and an anaerobic hybrid reactor. Reungsang et al. (2016) studied technology for methane fermentation in a USAB reactor using waste from a cassava starch manufacturing company in northeastern Thailand. The efficiency of chemical oxygen demand (COD) removal was 59.52%, which is relatively low. Tippayawong and Thanompongchart (2010) claimed that biogas from the anaerobic process digests 50-65% methane (CH_4) and 30-45% carbon dioxide (CO_2), moisture and hydrogen sulphide (H_2S). Rajeshwari et al. (2000) also reviewed the use of various biodegradable effluents such as sugar and distillery, pulp and paper, and slaughterhouse and dairy units, in the anaerobic digesting system.

Initially, we considered designing a biogas plant using AD BVF technology. Then, we realized that a low-rate system that combines features of the up-flow sludge blanket and anaerobic contact systems would be more effective. This system can treat most warm waste streams of moderate to very high organic strength and can efficiently remove 65% of COD (Fischer and Baches, 2014). This technology was originally developed in Canada; hence, to adopt this technology for use in Thailand, an additional cooling system must be added to make it suitable under tropical conditions to prevent overheating the gas engine. Moreover, the design must take earthquake and flood safety into consideration. This biogas technology is the same regardless of the types of plants employing it, such as ethanol plants, distilling plants or breweries. The only factors that differ are waste characteristics and quantity.

Phothong (2012) collected financial feasibility data though a surveying system concerning the operating costs, investment costs and other obstacles faced in biogas electricity generation in Thailand. The author also analysed the amount of governmental subsidies. He found that the private sector does not actually need subsidization because their NPVs are already greater than zero, even without financial support from the government. Vivanpatarakij et al. (2012) also studied the economic factors of 1 MW biogas power plants from energy crops. Tongsopit and Greacen (2013) have recommended short-term targets according to the 15-year renewable energy development plan (DEDE, 2015b). Targets have been reached for solar and biogas energy, but other renewables are still far from reaching their short-term targets. Promjiraprawat and Limmeechokchai (2012) agree that biogas-based plants would be effective in substantially reducing CO_2 emissions.

Suwanasri et al. (2015) introduced the biogas theory by suggesting key success factors to promote biogas utilization which include the integration of policy, technology, incentives and maintenance. Pepatung (2002) introduced H-USAB technology in treating waste water released from pig farms in Nakonpathom province. A farm releases approximately 2500 m^3 wastewater with 23,300 kg of COD per day. This amount of raw material can be used to produce 7000 m^3 of biogas with 65% methane that can be used to generate

6670 KWh of electricity. However, the investment cost for the wastewater treatment system is too high to achieve a payback period (PP) of <15 years and the internal rate of return (IRR) is substantially small.

From past studies, the FiT system seems to be the most effective method to calculate remuneration for private investors in the renewable energy generation business. In this study, we aim to determine the most suitable FiT scheme for private investors in biogas electric power generation in Thailand.

3. A SAMPLE DESIGN DATA OF A BIOGAS ELECTRICITY GENERATING PLANT

3.1. Existing Conditions of the System

Figure 1 shows an example of a typical wastewater treatment plant in Thailand. The wastewater from the factory is first discharged into an equalization pond (E1) for smoothing the inlet flow into the treatment process; it is then conveyed by pumps to a semi-aerobic lagoon and finally to an aerobic lagoon (E2-E13). Total retention time takes more than 100 days.

As shown in Table 1, the equalization pond (E1) collects wastewater for approximately 4 days. It is 2 m deep and has a capacity of 1118 m^3. The biochemical oxygen demand (BOD) coming to this pond is approximately 75,000 mg/L; COD is roughly 134,000 mg/L; and wastewater coming into this pond is roughly 300 m^3/day. The anaerobic lagoons (E2-E6) collected wastewater for about 105 days; they are 3 m deep. In these lagoons, we added bacteria to putrefy organic substances. In lagoons E7-E9 (facultative lagoons), wastewater was further processed for approximately 76 days at a depth of 2 m. In these ponds, the putrefying process is semi-aerobic, since the wastewater was already treated in lagoons E2-E6. The system includes two aerobic lagoons (E10-E11). The wastewater is collected here for 30 days. The depth is 1.5 m. Finally, the polishing lagoons (E12-E13) collect wastewater for 40 days at a depth of 1.5 m. These ponds employ a pasteurization process (E12-E13), since sunlight can penetrate through the water.

Table 1: List of wastewater treatment lagoons and digester

Lagoon no.	(EQ) E1	E2	E_N	E3	E4	E5	E6
Area (m^2)	1144	2305	1800	1360	2499	3965	6758
Depth (m)	2.5	2.7	8.0	2.8	2.8	4.3	3.2
Temperature (°C)	42.6	34.8		33.8	31.4	31.4	31.9
Lagoon no.	**E7**	**E8-9**	**E10**	**E11**	**E12**	**E13**	**Drying pond**
Area (m^2)	8447	5507	4437	3090	6300	3783	•
Depth (m)	2.2	3.9	4.5	3.8	4.9	3.7	(fluctuate)
Temperature (°C)	32.1	32.1	31.7	30.8	29.9	30.4	-

3.2. Process of Biogas

A biogas electric generation plant can be attached next to the equalization pond (EQ) which is the pond that treats wastewater in the first stage. As shown in Figure 2, the mist cooler system, cooling tower, deep well water pump and the AD BVF reactor were attached to the existing wastewater treatment system (zone E_N as indicated in the previous figure). Figure 2 shows the detailed layout of the biogas power plant.

Raw distillery wastewater is conveyed to the equalization pond in Zone A. From the equalization pond, the raw wastewater is pumped from Zone B through the mechanized cooling system at Zone C for screening and cooling. At Zone D, it passes through a de-scaling coil prior to entering the anaerobic reactor at Zone E. The wastewater enters the reactor beneath the sludge bed. The wastewater feed mixes with the recycle sludge according to an adjustable pumping schedule. As the wastewater passes upward through the sludge blanket, microorganisms attack the feed, digesting BOD, COD and total suspended solids while generating biogas. The spatial loading rate is low; therefore, it may be considered a low-rate up flow sludge blanket process. Most

Figure 1: General plot plan of the new wastewater treatment system (New condition E_N after project activity)

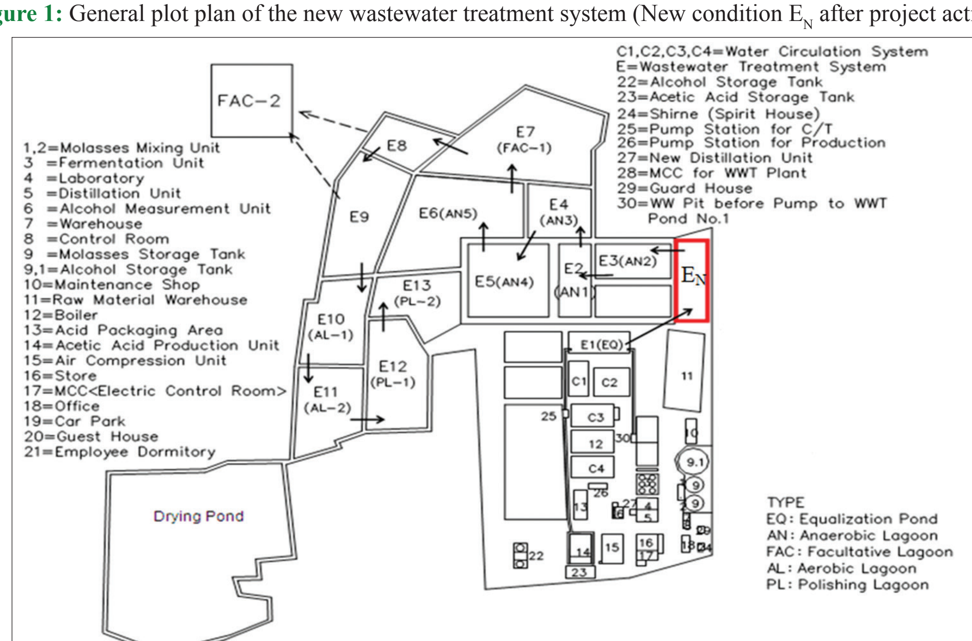
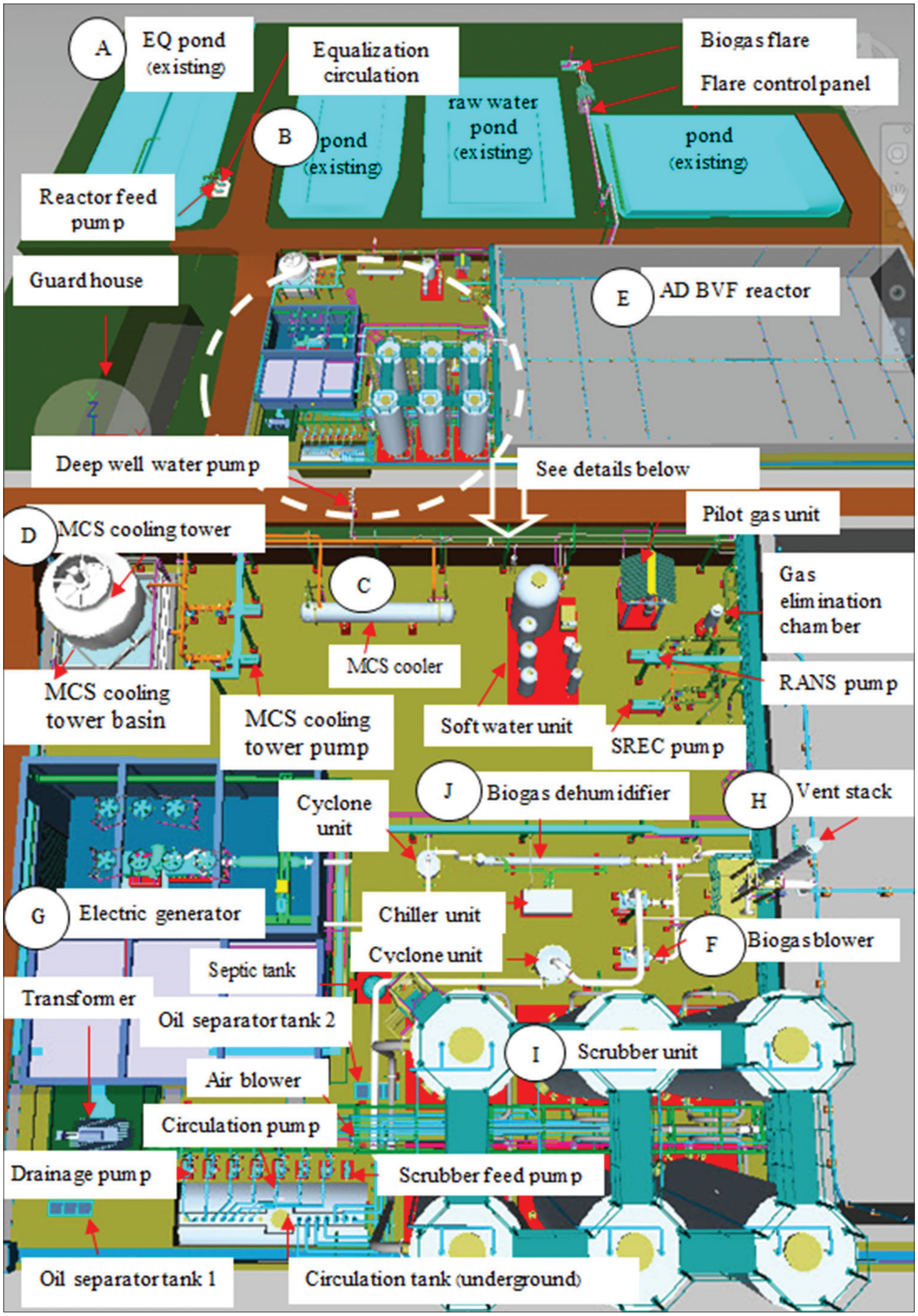


Figure 2: Three-dimesional model of general plot plan for biogas power plant



removal occurs in the primary reaction zone. Baffles are installed to discourage short-circuiting. Upon leaving the primary reaction zone, the wastewater passes through the secondary reaction zone, then through the clarification zone en route to the exit. With fewer BODs remaining, biological solids are able to settle into the sludge zone.

The effluent from the anaerobic reactor can simply be allowed to flow by gravity into existing effluent lagoons. The sludge recycle system comprises internal header-laterals, external piping and pumps that return sludge from the effluent end of the digester to the influent end. The same system is periodically used to transport waste sludge once the sludge bed occupies 50-70% of the reactor volume.

Biogas rises through the liquid, emerging at the gas-liquid interface just beneath a specially designed polymerized plastic cover. The biogas flows to the tank perimeter. A small negative pressure

Table 2: Parameter basis of wastewater, methane gas/biogas flow, generator set scale and electricity produced by the biogas generator

Item	Value	Unit
Wastewater basis		
Wastewater volume	300	m^3/day
COD of untreated wastewater	134	kgCOD/m^3
Days of releasing wastewater	335	days/yr
Methane gas/biogas flow		
Methane producing capacity (UNFCCC, 2015)	0.25	kgCH_4/kgCOD
Volume of one mole of any ideal gas at normal	22.4	Nm^3/kmol
Molecular mass of methane	16	kg/kmol
Digester COD removal efficiency	65	%
Methane gas flow per hour	381	Nm^3/h
Methane gas flow per day	9146	Nm^3/day
Methane gas flow per year	3,063,743	Nm^3/year
Biogas methane concentration	65	%
Biogas flow per hour	586	Nm^3/h
Biogas flow per day	14,070	Nm^3/day
Biogas flow per year	4,713,450	Nm^3/year
Generator set scale		
Methane calorific value	8550	kcal/Nm^3
Gas engine generating efficiency (Weiss et al., 2008)	36	%
Unit conversion	860.0	kcal/kWh
Total power input	3788	kW
Possible power generation	1364	kW
Determination power generation	1000	kW
Number of set	1	Set
Electricity produced by the biogas generator		
Digester and gene set operating days	335	days/year
Accident (failure) factor	5	%
Auxiliary electricity	10	%
Transmission loss	0.5	%
Electricity produced by the biogas generator unit for grid electricity replacement	6840	MWh/year
Auxiliary electricity consumed by the biogas plant	804.0	MWh/year

COD: Chemical oxygen demand

beneath the cover is maintained by means of biogas blowers at Zone F. This facilitates extraction of biogas and prevents the escape of odoriferous biogas into the environment. The speed of the blowers is automatically adjusted to match the rate of biogas production. Biogas then supplies the electricity generation system at Zone G. In case of emergency or if any excess biogas is generated, the biogas is burned by an open flare system at Zone H. However, excess gas at the flare can be negligible as the amount of biogas generated from the digester is equivalent to only 65% of the capacity of the gas engine (1364 MWe).

Prior to charging biogas into the gas engine, the biogas is de-sulfurized by means of a gas scrubber at Zone I. The treated biogas is passed through the dehumidifier unit at Zone J to eliminate moisture in the biogas and render it suitable for feeding into the gas engine at Zone G.

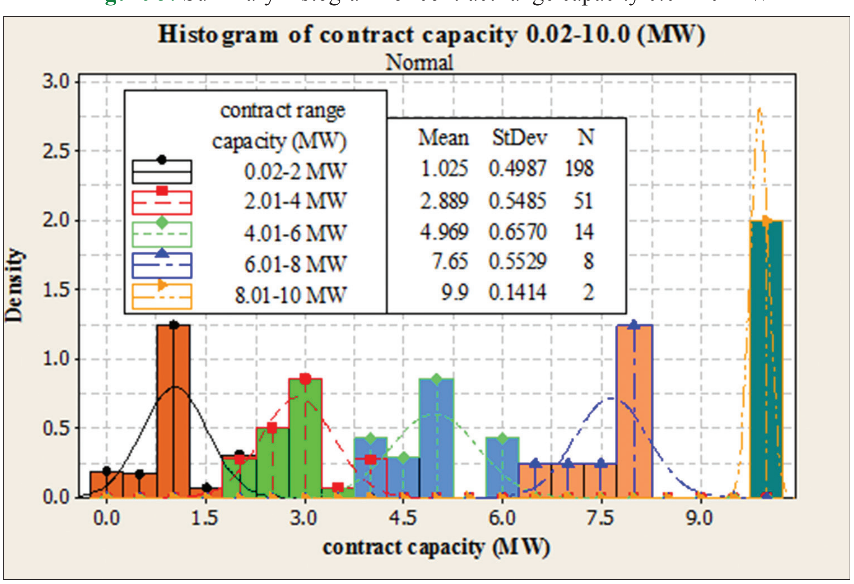
A summary of the raw material, generator specifications and electricity output is shown in Table 2.

4. METHOD, FINANCIAL ANALYSIS OF A BIOGAS ELECTRICITY GENERATING PLANT AND SOURCES OF DATA

In 2015, there were 273 VSPPs in Thailand (ERC, 2015). From this amount, 72.53% had the capacity to produce 0.02-2 MW of electricity at 198 plants; 18.68% had the capacity to produce 2.01-4.0 MW of electricity at 51 plants; 5.13% had the capacity to produce 4.01-6.0 MW of electricity at 14 plants; 2.93% had the capacity to produce 6.01-8.0 MW of electricity at 8 plants; and 0.73% had the capacity to produce 8.01-10 MW of electricity at 2 plants (Figure 3).

In order to establish a financial model for VSPPs, first we needed to measure revenues for investors. In our study, revenues consisted sales of electricity at the purchase price of 4.34 baht per KWh during peak, and 2.30 baht per KWh during off-peak (EGAT, 2015). These prices have been assumed to increase 1% point

Figure 3: Summary histogram for contract range capacity 0.02-10 MW



every year up to 20 years. Another source of revenues is derived from FiT, which is assumed to be at a constant rate throughout the first 8 years. In this study, we considered FiT of 0, 3, and 5 baht per KWh.

In addition to revenues from selling electricity and FiT, private investors can also obtain cash from greenhouse gas emission reductions. To calculate revenues from CERs, Equation (1) shows the parameters and calculations for the CDM in approved small scale methodologies using methane recovery in wastewater treatment (AMS-III.H, version 18; UNFCCC, 2015) and grid-connected renewable electricity generation (AMS-I.D, version 18; UNFCCC, 2014a) plus methodologies for calculating emission reductions (UNFCCC, 2015). Figure 4 shows our project boundaries in calculating CERs. The data used to calculate base line emissions (BE), project activity emissions (PE) and leakage emissions (LE) (UNFCCC, 2015) are shown in Table 3. No leakage calculations are specified because there are no leakage effects from equipment transfers from one unit to another within the project boundaries (LE). The carbon emission reductions (ER) show in Equation (1).

$$ER = BE - (PE + LE) \quad (1)$$

In this study, we calculated the total carbon emission reduction by considering all the processes required to treat wastewater. It was determined that total carbon emission reduction was 33,980 tCO_2e per year based on plant capacity of 1 MW. The unit price of carbon credit is 320 baht/tCO_2e (TGO, 2015). The revenue from selling carbon credits comes to 10,873,508 million baht per year. Total revenue from CERs for 20 years (extended every 7 years) is 217,472,000 baht (679,600 tCO_2e × 320 baht/tCO_2e).

In terms of costs, we began by quantifying labor costs as shown in Table 4. For the VSPP biogas plants, we estimated having at least one plant manager, one process engineer, one maintenance

Table 3: Calculation for CDM project for carbon emission reduction per 1 MW

Item	Value	Unit
Total baseline emissions		
Baseline methane emissions from an existing wastewater treatment		
MCF for anaerobic deep lagoon (depth>2 m) (UNFCCC, 2015)	0.8	-
GWP for methane (CH_4) (UNFCCC, 2015)	21	tCO_2/tCH_4
Baseline methane emission from an existing wastewater treatment	56,561	tCO_2e/year
Baseline electricity generation emissions		
Electricity produced by the biogas generator unit for grid electricity replacement	6840	MWh/yr
Grid emission factor	0.51	tCO_2e/MWh
Baseline electricity generation emissions	3488	tCO_2e/year
Total baseline emissions	60,050	tCO_2e/year
Total project emissions		
Emissions from electricity or diesel consumption		
Auxiliary electricity consumed by the biogas plant	804.0	MWh/yr
Emissions from electricity or diesel consumption	410	tCO_2e/yr
Methane emissions from wastewater treatment systems affected by the project activity and not equipped with biogas recovery in the project situation	0	tCO_2e/yr
Methane emissions from sludge treatment systems affected by the project activity and not equipped with biogas recovery in the project situation	0	tCO_2e/yr
Methane emissions from degradable organic carbon in treated wastewater		
Chemical oxygen demand of the treated wastewater	46.9	kgCOD/m^3
Model correction factor to account for model uncertainties	1.06	-
Methane emissions from degradable organic carbon in treated wastewater	19,796	tCO_2e/yr
Emissions from anaerobic decay of the final sludge produced		
Methane emissions from biogas release in capture systems		
COD loading	40,200	kgCOD/day
Methane emission potential of wastewater treatment systems equipped with biogas recovery system (sludge volume in reactor is approximately 7-8% of COD loading)	2,814	kgCOD/day
Degradable organic content of the final sludge generated by wastewater treatment in the year (UNFCCC, 2015)	0.09	
Methane correction factor of the landfill that receives the final sludge (UNFCC, 2014b)	0	
Fraction of DOC dissimilated to biogas (DOCF) (UNFCCC, 2015)	0.5	
Fraction of CH4 in landfill gas (UNFCCC, 2015)	0.5	
Methane emissions from anaerobic decay of the final sludge produced	0	tCO_2e/year
Emissions from methane release in capture and flare systems		
Capture efficiency of the biogas recovery equipment in the wastewater treatment systems (UNFCCC, 2015)	90	%
Emissions from methane release in capture and flare systems	5656	tCO_2e/year
Emissions from dissolved methane in treated wastewater		
Dissolved methane content in the treated wastewater (UNFCCC, 2015)	0.0001	tonnes/m^3
Emissions from dissolved methane in treated wastewater	211	tCO_2e/year
Total project emissions	26,070	tCO_2e/year
Leakage	0	tCO_2e/year
Carbon emission reduction	33,980	tCO_2e/year

MCF: Methane correction factor, GWP: Global warming potential engineer, and one scientist. We also required quality control staff and plant operators. The total labor cost is assumed to increase 7% per year.

The corporate income tax rate of 30% per year is exempt during the first 8 years of operation. Later on, there will be a 50% reduction of the corporate income tax according to the BOI investment promotion (BOI, 2015).

The investment costs consist of equipment, material supply, engineering, civil and architecture and indirect costs as shown in Table 5. The total investment cost is approximately 180 million baht. If we include the working capital, contingency costs of 5%, and any additional costs, the total investment is expected to be approximately 200 million baht as shown in Table 6. We will consider performing sensitivity analysis for this investment cost. Hence, cases where investment is ±20% than expected will be

Table 4: Labor costs per year

Annual salary	Unit cost	Unit	Quality	In '000 baht
Plant manager	70,000	baht/month	1	840
Process engineer	35,000	baht/month	1	420
Maintenance engineer	35,000	baht/month	1	420
QC scientist	30,000	baht/month	1	360
QC and laboratory chief	25,000	baht/month	2	600
Production chief	25,000	baht/month	2	600
M/T chief	25,000	baht/month	2	600
QC technician	15,000	baht/month	4	720
Production operator	15,000	baht/month	4	720
M/T technician (electrical and instrument)	15,000	baht/month	4	720
M/T technician (mechanical)	15,000	baht/month	4	720
Worker	7000	baht/month	8	672
Total labor cost per year				7392

QC: Quality control

Figure 4: Project boundary

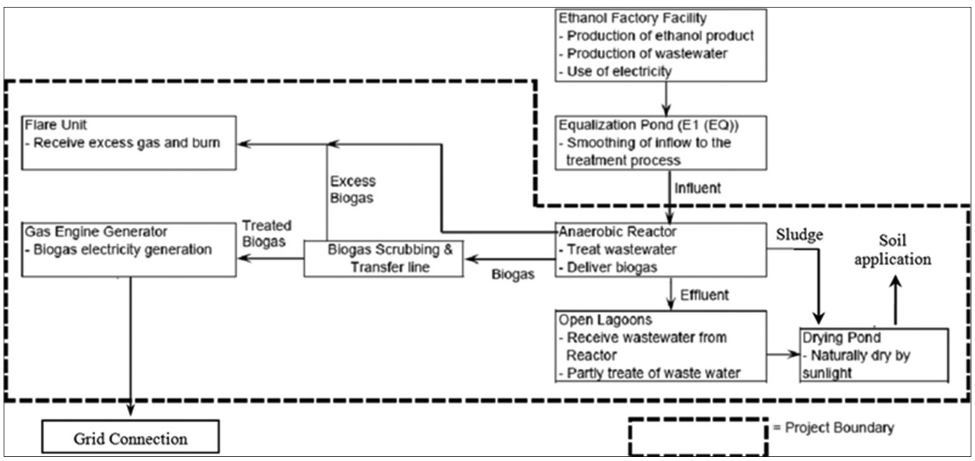


Figure 5: Boxplots for the case of 0.02-2.0 MW when feed-in-tariff = 0 baht per KWh of (a) Net present value (NPV) (MB) using discounting rate of 12%, (b) NPV (MB) using discounting rate of 14%, (c) internal rate of return (%)

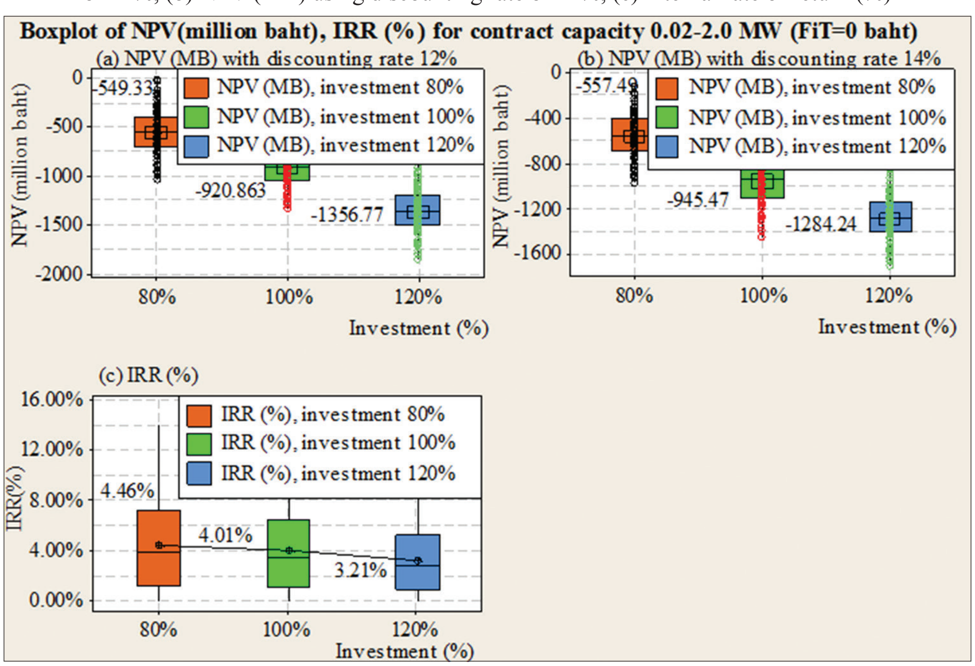


Table 5: Engineering procurement construction price breakdown per 1 MW

AD (equipment and material supply)		=38,430,000.00 ฿
Positive displacement blower		
Cover pressure transmitter		
Enclosure to house pressure transmitter complete with manometer		
Low pressure drip traps		
Drop oilers		
Sediment moisture trap		
Standard biogas flare system (burner) and control system		
Flame trap assembly with thermal shut-off valve		
Personnel gas monitor		
Draeger manual biogas composition measurement equipment		
Hand-held Oxor II automatic oxygen content analyzer		
AD for sludge profiling		
Kemmerer sampler for collecting samples from reactor		
Sludge gun for determining height of sludge blanket		
Instrument and control system		
XR-5 Geomembrane Cover		= 1,500,000.00
Engineering		=5,400,000.00 ฿
Basic engineering/balance of plant		
Equipment and Material		=85,950,000.00 ฿
Piping	1,250,000.00	
MCS, pump, mixer cooling, etc.,	10,116,000.00	
Flare System (stack and others)	630,000.00	
Electrical system	1,304,000.00	
Instruments and controls for process	4,230,000.00	
Monitoring instrument and laboratory equipment	4,500,000.00	
Generator (1000 kW)	20,520,000.00	
H_2S scrubber (550 Nm^3/h)	1,340,000.00	
Chiller	3,060,000.00	
Electricity connection/synchronize system and transformer	8,190,000.00	
Installation of electrical connection system	810,000.00	
Civil and architecture		=48,600,000.00 ฿
RC Reactor Pond (14,000 m3)	36,288,000.00	
Cooling Basin	540,000.00	
Scrubber/Chiller Foundation	2,340,000.00	
M.C.S. Equipment Foundation	855,000.00	
Building for Office, Laboratory and Generator set	783,000.00	
P/R, Sleeper, Local foundation	3,474,000.00	
Fence and Gate	1,800,000.00	
Road and Paving	1,458,000.00	
Drum Seal Pit	207,000.00	
Office and Laboratory Furniture	675,000.00	
Government approval	180,000.00	
Indirect cost		=5,400,000.00 ฿
Site preparation	900,000.00	
Temporary office, facilities and utilities	1,183,500.00	
Field office aid	731,700.00	
Storing	774,000.00	
Field expenses	1,296,000.00	
Construction supervisor	2,178,000.00	
Project employees	1,116,000.00	
Project M/P	1,152,000.00	
Project coordination EX, MOE, TGO, PEA, DNRE and TAO	996,300.00	
Finance costs	167,400.00	
Contingency	2,277,000.00	
Overhead and profit	1,836,000.00	
Escalation risk	531,000.00	
Insurance	636,300.00	
Stamp/duty	189,000.00	
Withholding tax	5,454,000.00	
EPC grand total		=183,780,000.00 ฿

EPC: Engineering procurement and construction

considered. Table 6 summarizes not only the investment costs, but also revenues and operating costs.

We have employed Monte Carlo simulation to model uncertainties about the amount of electricity generation from biogas power plant. During the simulation method, we first tried to determine a suitable distribution for each range of contract capacity. If we find suitable distribution with α = 0.05, we will use the distribution to simulate the amount of electricity that the plant will generate in a given year. However, if no distribution matches our historical data, we will simulate the amount of electricity generated based on the discrete nature of the data. As mentioned earlier, we also

Table 6: Summary of investment, revenue and costs per 1 MW

Item	Baht
Total initial investment	
EPC price	183,780,000
Contingency 5% (owner)	9,189,000
Working capital	5,000,000
Total initial establishment	2,000,000
CDM expense (PDD, etc.)	1,000,000
Total initial investment	200,969,000
Revenue	
Electric power	
Purchase power price (baht per kWh at Peak) (EGAT, 2014)	4.34
Electric power revenue (4.34 [baht/kWh]×6,840,000 [kWh/y])	29,684,858
CERs	
CERs price (baht/tCO_2e) (TGO, 2015)	320
CER revenue	10,873,508
Total revenue	40,558,366
Costs	
Manpower costs	7,392,000
Consumables	500,000
System maintenance	460,000
Gas engine maintenance	2,430,000
CDM monitoring	500,000
Total cost	11,282,000

EPC: Engineering procurement and construction, PDD: Project design document, CER: Constant exchange rates

consider cases when investment cost is ±20% of the original cost and consider different discount rates of 12% and 14%.

For the contract capacity of 0.02-2.0 MW, the results of NPV (MB), IRR (%), PP (years) and profitability index (PI) when FiT = 0, 3 and 5 baht per KWh are shown in Figures 5-10.

As shown in Figures 5-10, we determined that when FiT is zero, all indicators show that the business is very unattractive. When FiT is increased to 3 baht per KWh, the indicators reveal that the investment is attractive only when the investment cost is 80% of the original estimation. If the investment cost is close to the estimation, the business is attractive when the discounting rate is assumed to be 12%. When FiT is 5 baht per KWh, all indicators show that investment is very attractive even when the investment cost is increased by 20%. Hence, if the government is serious about promoting biogas business, a subsidy of 5 baht per KWh is very reasonable.

Figure 11 shows the distribution of NPVs and IRRs when FiT is 5 baht per KWh, investment is 100% and discounting rate is 14%. Figure 11a shows that NPVs have a Weibull distribution while Figure 11b shows that IRRs have a normal distribution. Figure 11c and d also show the probability is very close to one that NPVs are greater than zero when FiT is 5 baht per KWh. The chance that IRRs are >14% is 88.46%.

Figures 12-15 show the results when contract capacity is 2.01-4.00 MW of the NPV (MB), IRR (%), PP (year) and PI when FiT = 0 and 3 baht per KWh. As shown in these Figures 12-15, FiT of 3 baht per KWh is already sufficient, while FiT of 0 baht per KWh still shows negative potential when investment cost is higher than the approximation.

Figure 6: Boxplots for the case of 0.02-2.0 MW when feed-in-tariff = 0 baht per KWh of: (a) Payback period (PP) (years) using discounting rate of 12%, (b) PP (years) using discounting rate of 14%, (c) profitability index (PI) using discounting rate of 12% (d) PI using discounting rate of 14%

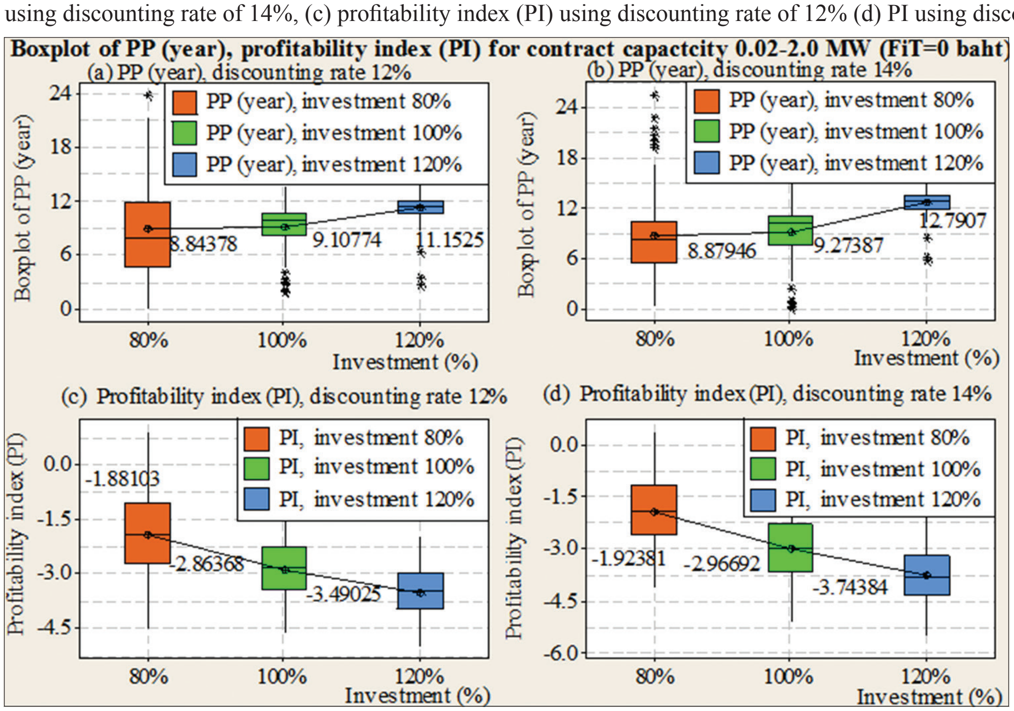


Figure 7: Boxplots for the case of 0.02-2.0 MW when feed-in-tariff = 3 baht per KWh of: (a) Net present value (NPV) (MB) using discounting rate of 12% (b) NPV (MB) using discounting rate of 14% (c) internal rate of return (%)

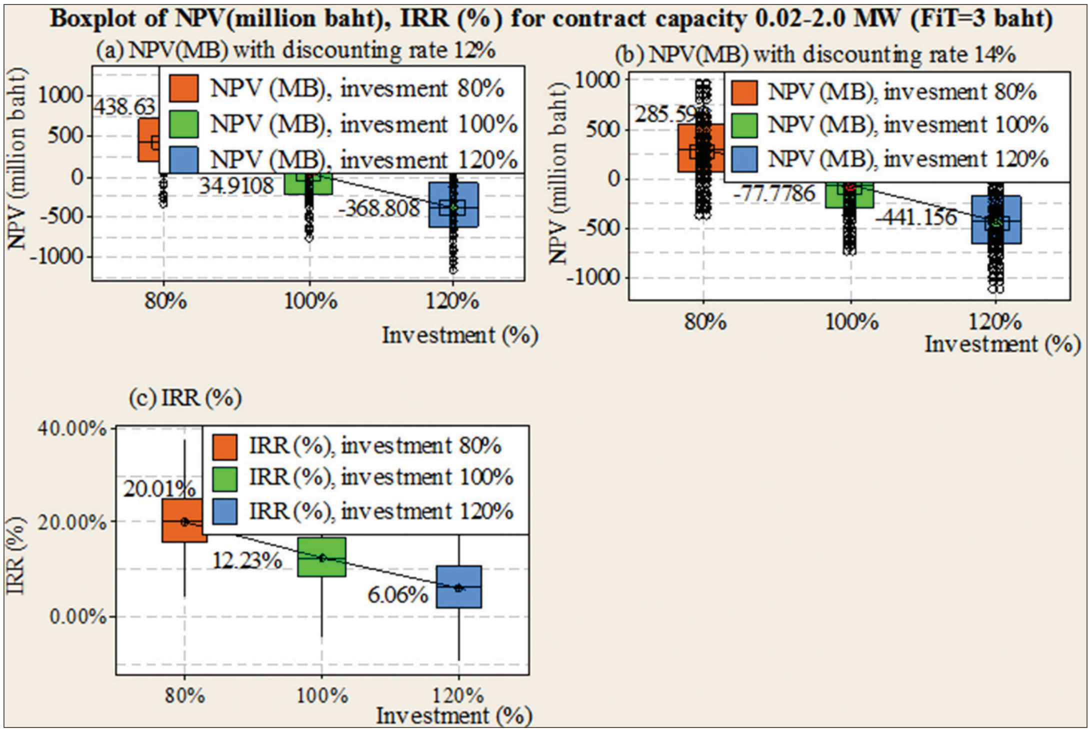
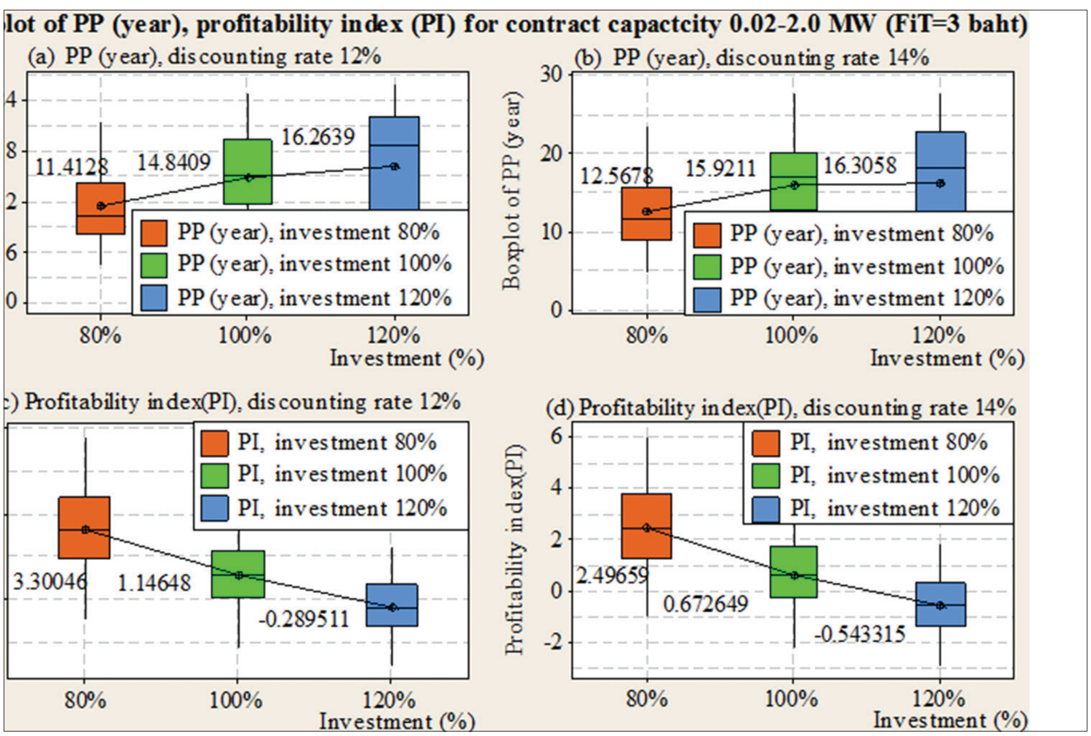


Figure 8: Boxplots for the case of 0.02-2.0 MW when feed-in-tariff = 3 baht per KWh of (a) payback period (PP) (years) using discounting rate of 12% (b) PP (years) using discounting rate of 14% (c) profitability index (PI) using discounting rate of 12% (d) PI using discounting rate of 14%



Figures 12-15 show that when FiT is 3 baht per KWh, the investment is definitely attractive. However, when FiT is 0 baht per KWh, there could still be a case when the investment is 20% higher than the original estimation when the discounting rate is 14%. In fact, FiT may not need to be as high as 3 baht per KWh since the investment is attractive even when FiT is zero.

Figure 9: Boxplots for the case of 0.02-2.0 MW when feed-in-tariff = 5 baht per KWh of (a) net present value (NPV) (MB) using discounting rate of 12% (b) NPV (MB) using discounting rate of 14% (c) internal rate of return (%)

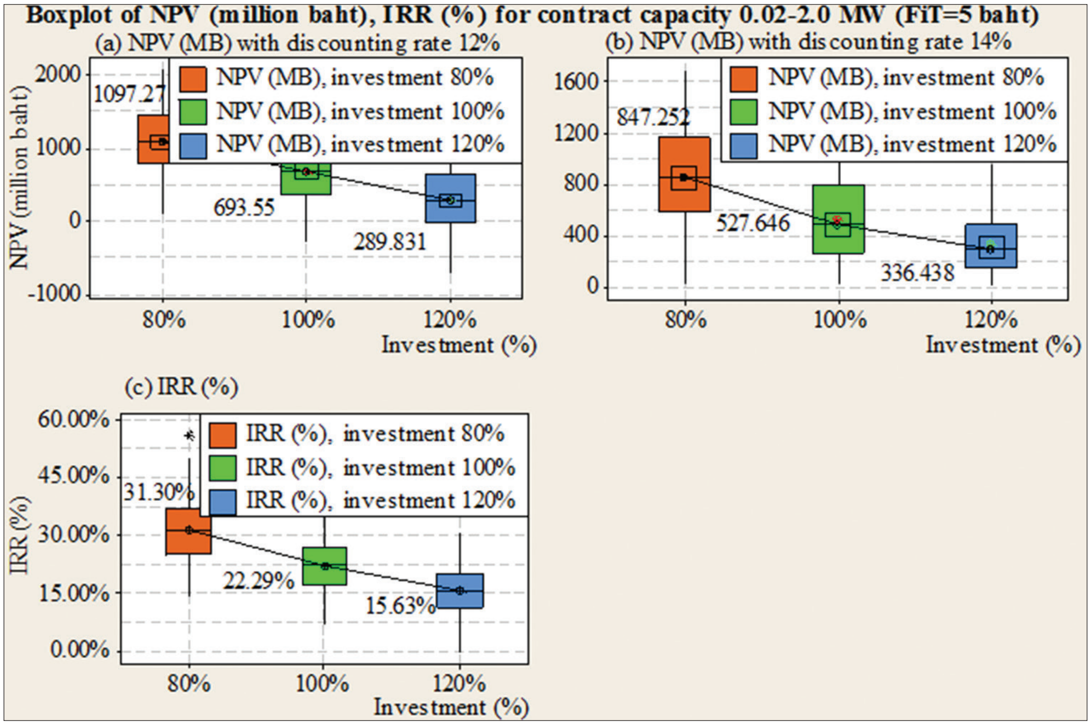


Figure 10: Boxplots for the case of 0.02-2.0 MW when feed-in-tariff = 5 baht per KWh of: (a) Payback period (PP) (years) using discounting rate of 12% (b) PP (years) using discounting rate of 14% (c) profitability index (PI) using discounting rate of 12% (d) PI using discounting rate of 14%

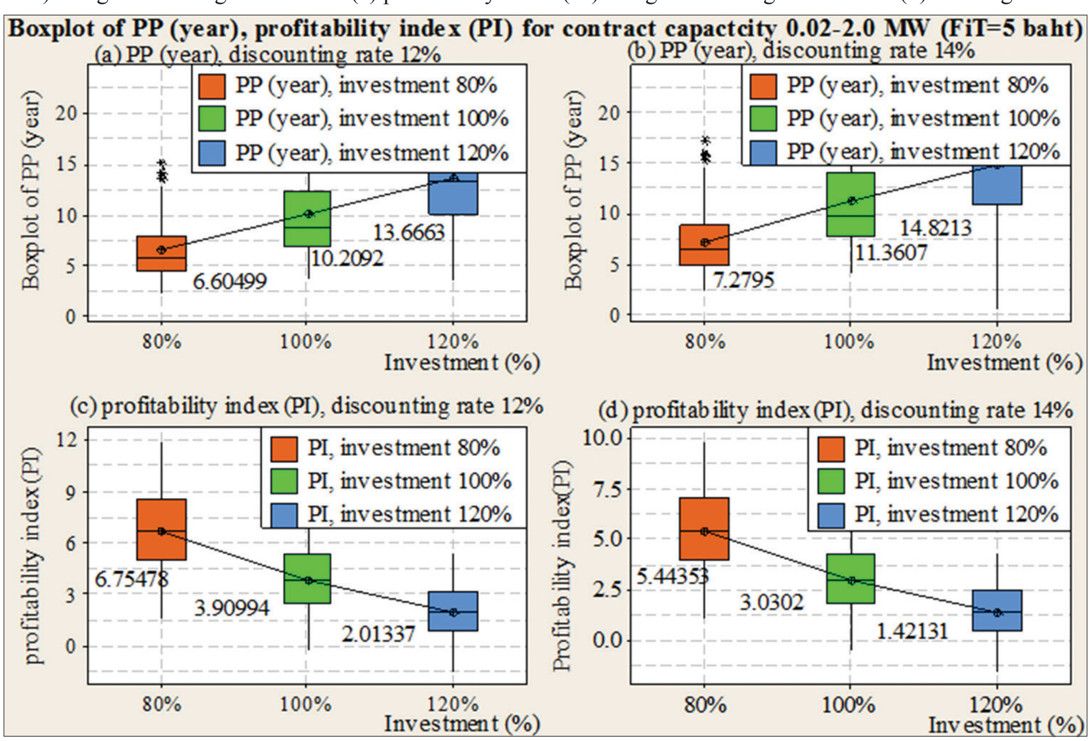


Figure 16 shows the distribution of the NPVs and IRRs when FiT equals 3 baht per KWh. Both NPVs and IRRs have highest extreme value distributions. The probability is almost 1 that NPVs are greater than zero. The probability that IRRs are >14% is 100%.

Figure 17 shows the results when contract capacity is 4.01-6.0 MW and FiT equals to zero. In this Figure 17, the probability is almost 1 that the NPV is greater than zero and the resulting NPVs have a 3-parameter Weibull distribution. On the other hand, IRRs have

Figure 11: Histograms and distribution plots when contract capacity is 0.02-2.0 MW and when feed-in-tariff = 5 baht per KWh where: (a) Histogram of the net present value (NPVsv) (MB) using discounting rate of 14%, (b) histogram of the internal rate of returns (IRRs) (%), (c) distribution plot of the NPVsv (MB) using discounting rate of 14%, (d) distribution plot of the IRRs (%)

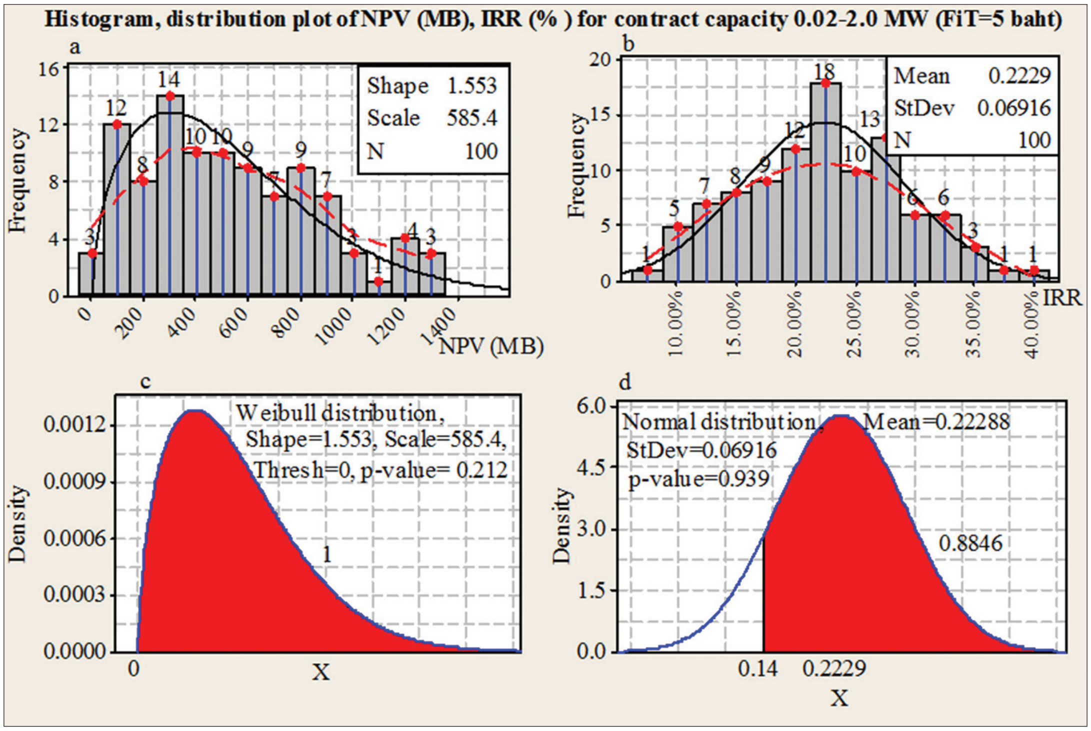
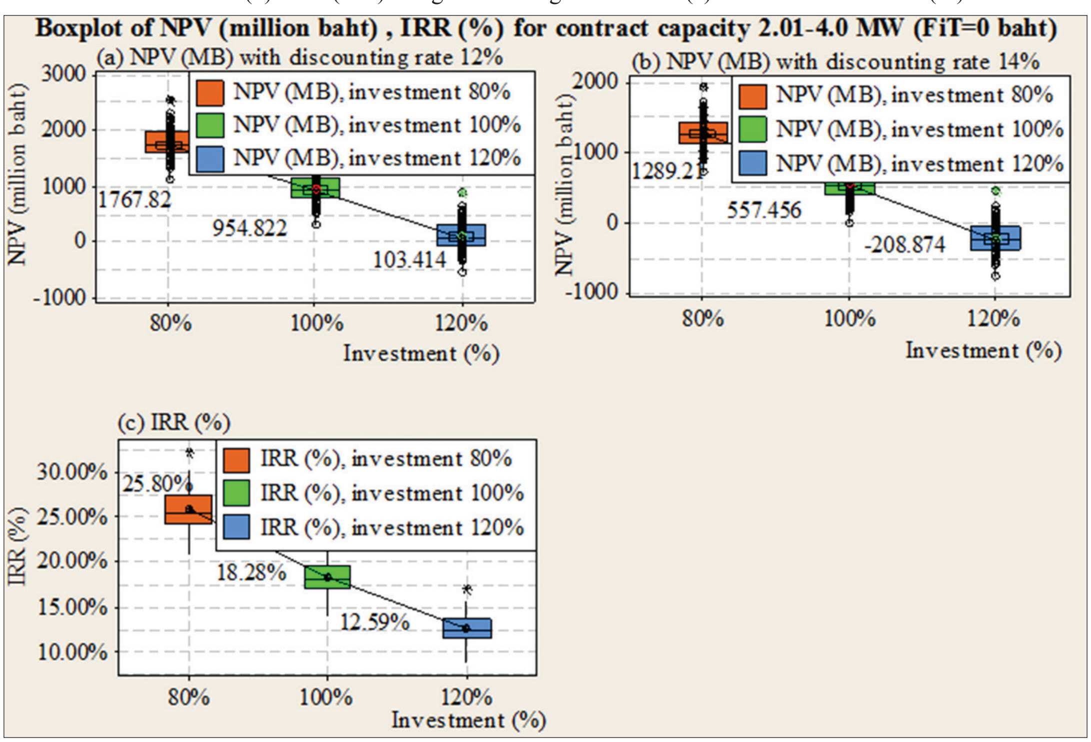


Figure 12: Boxplots for the case of 2.01-4.0 MW when feed-in-tariff = 0 baht per KWh of: (a) Net present value (NPV) (MB) using discounting rate of 12% (b) NPV (MB) using discounting rate of 14% (c) internal rate of return (%)



normal distribution and the probability is almost 1 that IRRs are >14%.

Finally, for contract capacity of 6.01-10.00 MW, all indicators show that private investors can be successful in doing biogas

Figure 13: Boxplots for the case of 2.01-4.0 MW when feed-in-tariff = 0 baht per KWh of: (a) Payback period (PP) (years) using discounting rate of 12%, (b) PP (years) using discounting rate of 14%, (c) profitability index (PI) using discounting rate of 12% (d) PI using discounting rate of 14%

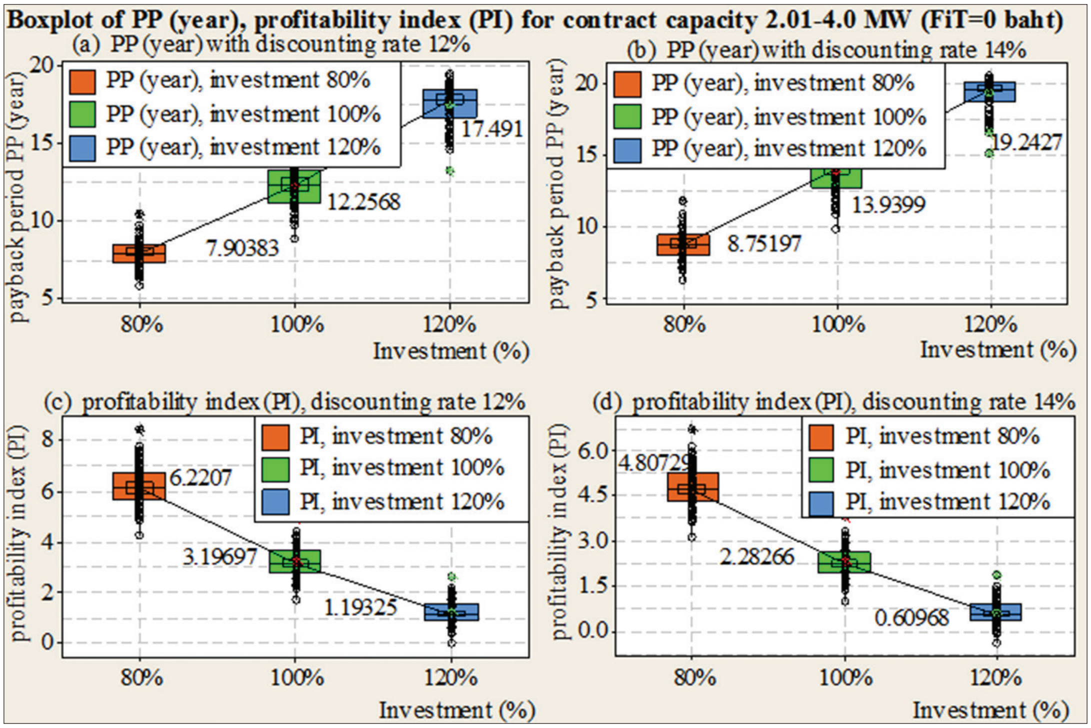
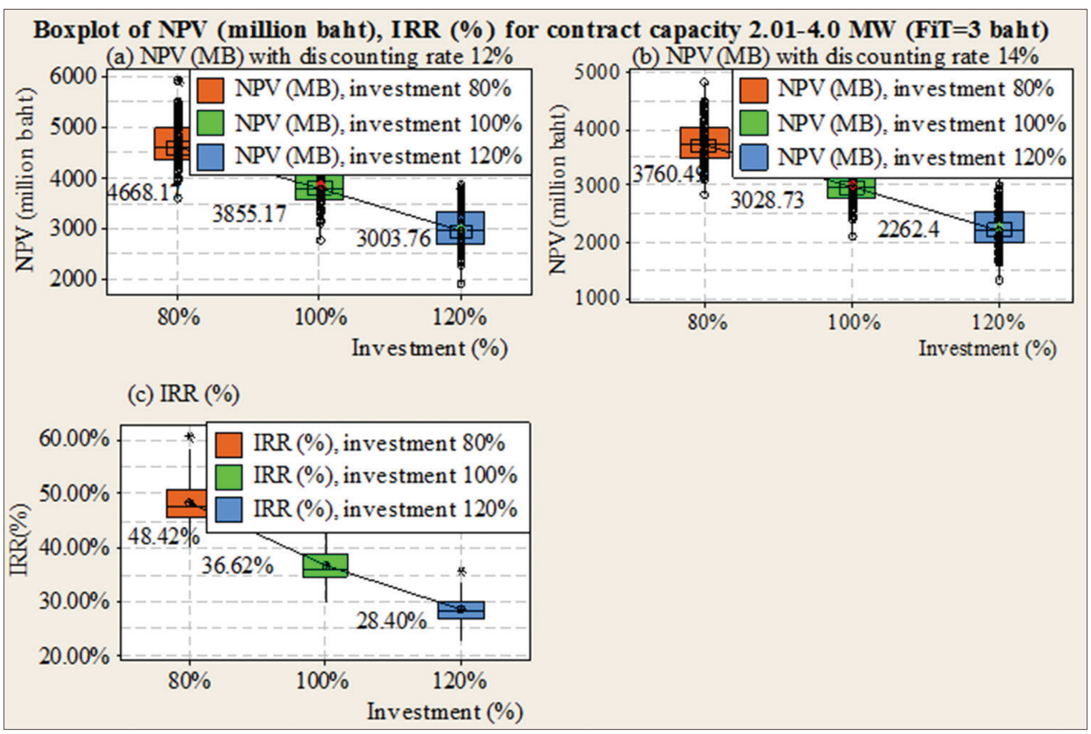


Figure 14: Boxplots for the case of 2.01-4.0 MW when feed-in-tariff = 3 baht per KWh of: (a) Net present value (NPV) (MB) using discounting rate of 12%, (b) NPV (MB) using discounting rate of 14%, (c) internal rate of return (%)



business even without government remuneration. The results in these cases are similar to when contract capacity is 4.01-6.0 MW as explained in the previous case. Therefore, we have omitted showing graphs for contract capacity that is higher than 6 MW.

Figures 18 and 19 summarize the histogram of NPV (discounting rate of 14%), IRRs, payback period (discounting rate of 14%), and profitability index (discounting rate of 14%) for all ranges of contract capacity when FiT is zero.

Figure 15: Boxplots for the case of 2.01-4.0 MW when feed-in-tariff = 3 baht per KWh of: (a) Payback period (PP) (years) using discounting rate of 12% (b) PP (years) using discounting rate of 14% (c) profitability index (PI) using discounting rate of 12% (d) PI using discounting rate of 14%

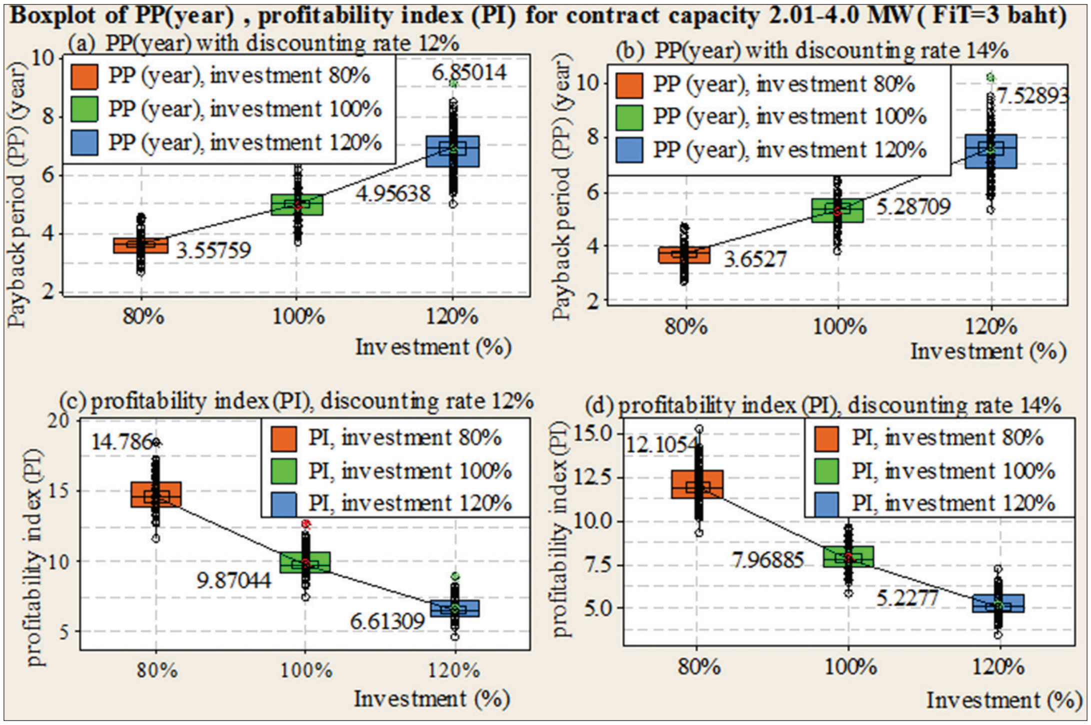
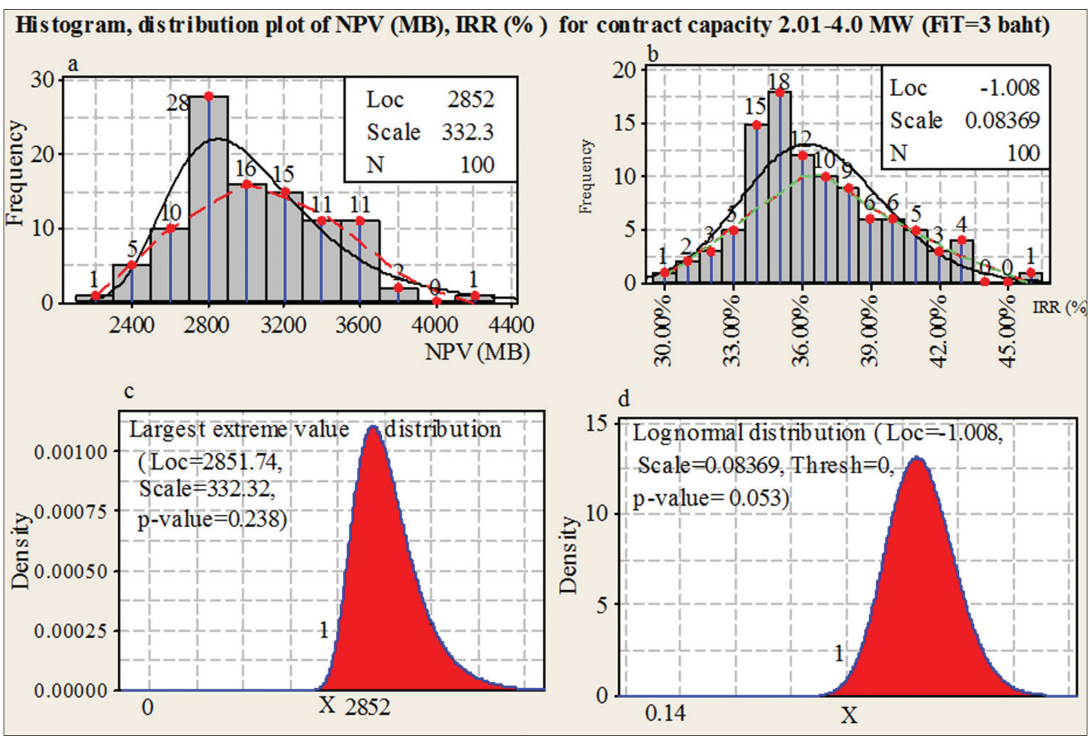


Figure 16: Histograms and distribution plots when contract capacity is 2.01-4.0 MW and when feed-in-tariff = 3 baht per KWh where: (a) Histogram of the net present value (NPVsv) (MB) using discounting rate of 14%, (b) histogram of the internal rate of returns (IRRs) (%), (c) distribution plot of the NPVsv (MB) using discounting rate of 14%, (d) distribution plot of the IRRs (%)



5. CONCLUSION

In this study, we have provided a sample design with explanation of existing biogas plants that can actually be applied to various kinds of plants. The financial analysis was carefully conducted. The results show that in order to promote biogas business in Thailand, the government should provide FiT remuneration of 5 baht per KWh when contract capacity is 0.02-2 MW. When contract capacity is increased to be >2 MW, but <4 MW, the FiT remuneration can be reduced to 3 baht per KWh per MW.

Figure 17: Histograms and distribution plots when contract capacity is 4.01-6.0 MW and when feed-in-tariff = 0 baht per KWh where: (a) Histogram of the net present value (NPVsv) (MB) using discounting rate of 14%, (b) histogram of the internal rate of returns (IRRs) (%), (c) distribution plot of the NPVsv (MB) using discounting rate of 14%, (d) distribution plot of the IRRs (%)

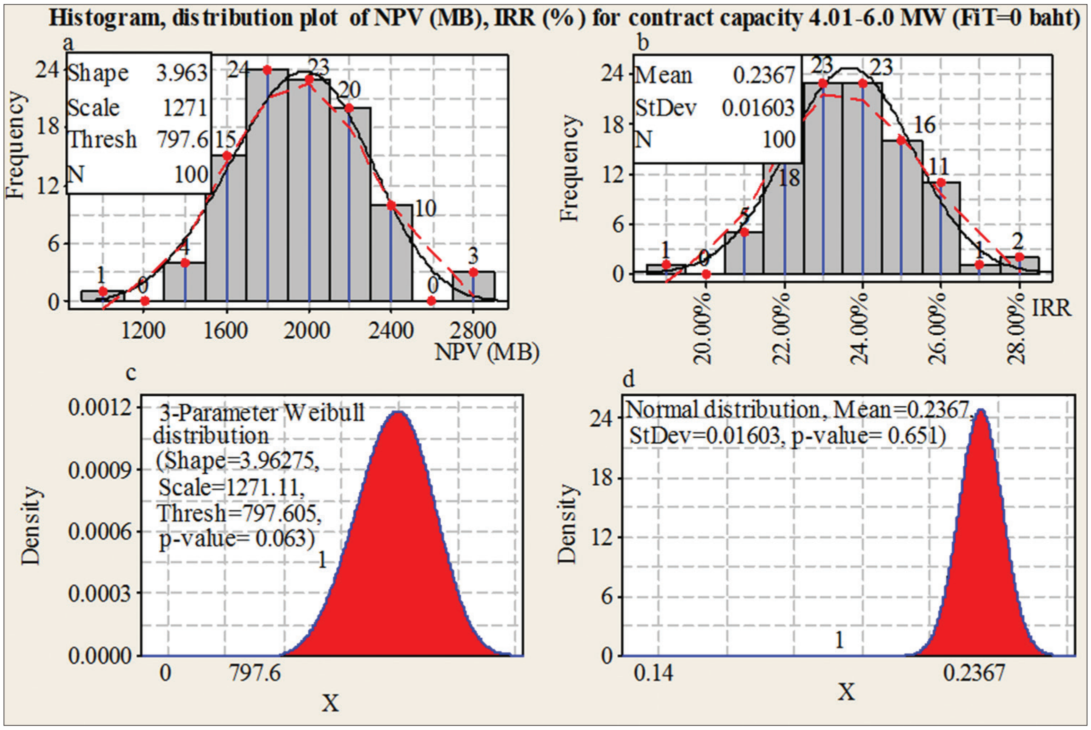
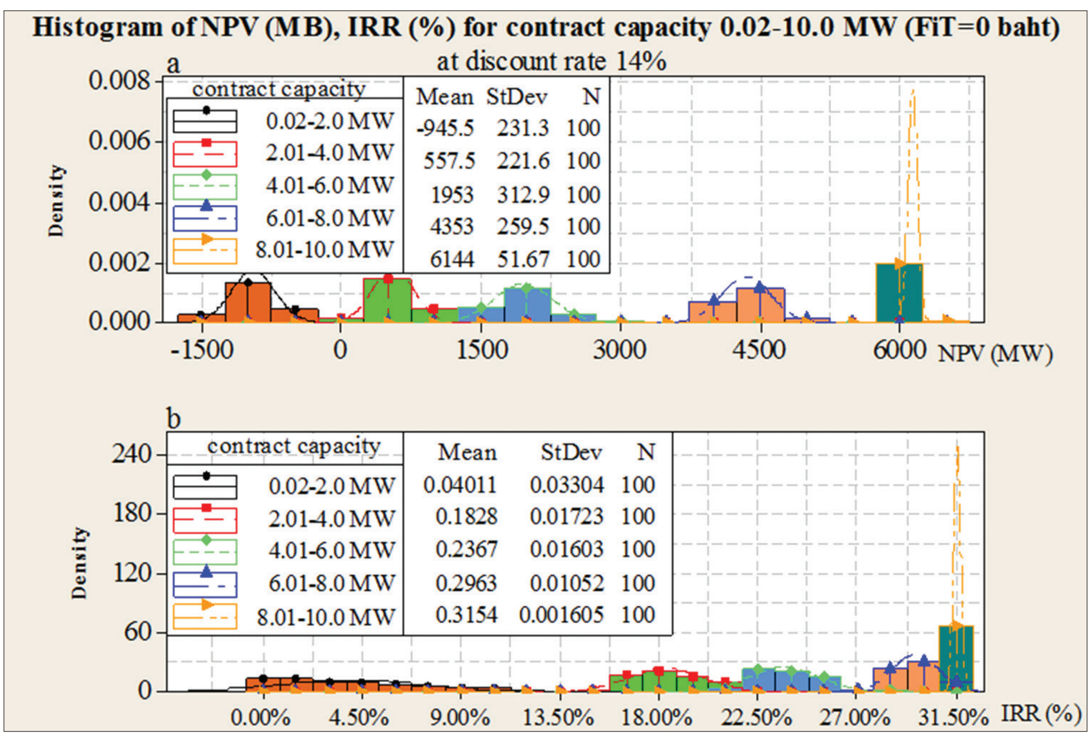


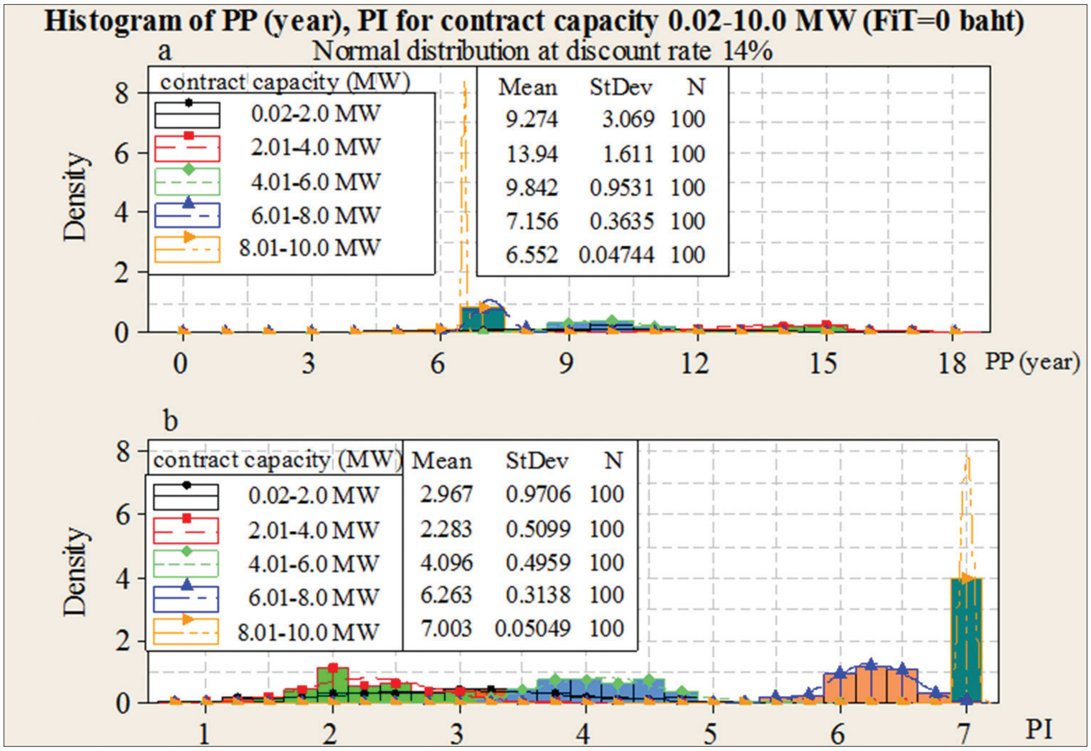
Figure 18: Histograms of the entire range when feed-in-tariff = 0 baht per KWh where: (a) Histogram of net present value (NPV) (MB) using discounting rate of 14%, (b) histogram of internal rate of return (%)



However, when contract capacity is >4 MW, the government need not provide any FiT remuneration. In contrast, Phothong (2012) determined that there was no need for the government to subsidize any contract capacity ranges for VSPP.

Even though we determined suitable FiT remunerations for biogas power plants, there are still some concerns regarding this business such as the lack of transmission lines, limited number of power purchase agreements issued by the government (Keyuraphan et al.,

Figure 19: Histograms of the entire range when feed-in-tariff = 0 baht per KWh where: (a) Histogram of payback period (years) using discounting rate of 14%, (b) histogram of profitability index using discounting rate of 14%



2012), instability of the supply of raw material, and regulations concerning town zoning in Thailand. Hence, designing a proper transmission system for renewable energy could be another interesting study to expand the production of electricity using biogas in Thailand. This study can also be further adapted to determine FiT remunerations for other types of renewable energy generating plants in Thailand such as waste, wind and solar. Finally, since the government budget is a limited resource, determining the optimal FiT across various types of renewable energy is also necessary.

REFERENCES

Aidan, D., Rogers, M., Ayompe, L. (2015), Renewable Energy and Energy Efficiency: Assessment of Projects and Policies. West Sussex, United Kingdom: John Wiley & Sons, Ltd.

Board of Investment, (BOI). (2015), A Guide to the Board of Investment 2015. Available from: http://www.boi.go.th/upload/content/BOI-A%20Guide%202015-EN-20151202_47427.pdf. [Last accessed on 2016 Feb 10].

Chaiprasert, P. (2011), Biogas production from agricultural wastes in Thailand. Journal of Sustainable Energy & Environment, (Special Issue), 63-65.

Couture, T., Gagnon, Y. (2010), An analysis of feed-in tariff remuneration models: Implications for renewable energy investment. Energy Policy, 38, 955-965.

DEDE, Department of Alternative Energy Development and Efficiency. (2015a), Alternative Energy Development Plan 2015. Available from: http://www.dede.go.th/download/files/AEDP2015_Final_version.pdf. [Last accessed on 2016 Feb 10].

DEDE, Department of Alternative Energy Development and Efficiency. (2015b), Renewable Energy Development Plan (15 Years): 2015-2036. Available from: http://www.biogas.dede.go.th/biogas/web_biogas/app.html. [Last accessed on 2016 Feb 10].

EGAT, Electricity Generating Authority of Thailand. (2015), About EGAT 2016. Available from: http://www.egat.co.th/en. [Last accessed on 2016 Feb 10].

EPPO, Energy Policy and Planning Office. (2015), PDP 2015. Available from: http://www.eppo.go.th/power/PDP2015/PDP2015_Eng.pdf. [Last accessed on 2016 Feb 10].

ERC, Energy Regulatory Commission. (2015), Policy and Development Plan for Power Generation of Thailand PDP 2015.

Fischer, T., Baches, K. (2014), How to Organize a Biogas Project in Thailand. Germany: Krieg & Fischer Ingenieure GmbH, Göttingen. Available from: http://www.kriegfischer.de/fileadmin/kriegfischer/public/docs/veroeffentlichungen/Abstract_Biogashandbuch_Thailand.pdf. [Last accessed on 2016 Feb 10].

INDC, Intended Nationally Determined Contribution. (2015), Thailand's Intended Nationally Determined Contribution. Available from: http://www.4.unfccc.int/submissions/INDC/Published%20Documents/Thailand/1/Thailand_INDC.pdf. [Last accessed on 2016 Feb 10].

Keyuraphan, S., Thanarak, P., Ketjoy, N., Rakwichian, W. (2012), Subsidy schemes of renewable energy policy for electricity generation in Thailand. Procedia Engineering, 32, 440-448.

Limmeechokchai, B. (2012), Study on appropriate feed-in tariffs and macroeconomic impact by energy input-output analysis. The Thailand Research Fund.

Pepatung, N. (2002), The alternative utilization of biogas from a central treatment Plant of pig and food SME wastewater in Nakhon Phathom Province. Master Thesis. Thon Buri, Thailand: King Mongkut's University of Technology.

Pita, P., Tia, W., Suksuntornsiri, P., Limpitipanich, P., Limmeechockchai, B. (2015), Assessment of feed-in tariff policy in Thailand: Impacts on national electricity porices. 2015 International Conference on Alternative Energy in Developing Countries and Emerging Economies. Energy Procedia, 79, 584-589.

Phothong, B. (2012), A Study of Supportive Factors of the Renewable Energy in Thailand. Master Thesis. Thailand: KhonKaen University, Renewable Energy Engineering Department.

Promjiraprawat, K., Limmeechokchai, B. (2012). Assessment of Thailand's energy policies and CO_2 emissions: Analyses of energy efficiency measures and renewable power generation. Energies, 5(8), 3074-3093.

Ragwitz, M., Winkler, J., Klessmann, C., Gephart, M., Resch, G. (2012), Recent Developments of Feed-in Systems in the EU: A Research Paper for the International Feed-In Cooperation. Germany: Energy Economics, Group & Fraunhofer, Institute Systems and Innovation Research. Available from: http://www.feed-in-cooperation.org/wDefault_7/download-files/research/101105_feed-in_evaluation_update-January-2012_draft_final_ISI.pdf. [Last accessed on 2016 Feb 10].

Rajeshwari, K.V., Balakrishnan, M., Kansal, A., Lata, K., Kishore, V.V.N. (2000), State-of-the-art of anaerobic digestion technology for industrial wastewater treatment. Renewable & Sustainable Energy Reviews, 4, 135-156.

Reungsang, A., Sittijunda, S., Sreela-or, C. (2016), Methane production from acidic effluent discharged after thehydrogen fermentation of sugarcane juice using batch fermentation and UASB reactor. Renewable Energy, 86, 1224-1231.

Suwanasri, K., Trakulvichean, S., Grudloyma, U., Songkasiri, W., Commins, T., Chaiprasert, P., Tanticharoen, M. (2015), Biogas – Key success factors for promotion in Thailand. Journal of Sustainable Energy & Environment, (Special Issue), 25-30.

TGO, Thailand Greenhouse Gas Management Orgnization. (2015), CDM Statistics. Available from: http://www.conference.tgo.or.th/download/tgo_or_th/Statistic/2015/Oct/CDM/sumIII_16_Oct_th.pdf. [Last accessed on 2016 Feb 10].

Tippayawong, N., Thanompongchart, P. (2010), Biogas quality upgrade by simultaneous removal of CO_2 and H_2S in a packed column reactor. Energy, 35, 4531-4535.

Tongsopit, S., Greacen, C. (2013), An assessment of Thailand's feed-in tariff program. Renewable Energy, 60, 439-445.

Tongsopit, S., Kittner, N., Chang, Y., Aksornkija, A., Wangjiraniran, W. (2016), Energy security in ASEAN: A quantitative approach for sustainable. Energy Policy, 90, 60-72.

Ueasin, N., Wongchai, A., Nonthapot, S. (2015), Assessment and optimization of biomass steam turbine power plants by data envelopment analysis. International Journal of Energy Economics and Policy, 5(3), 668-672.

UNFCCC. (2014a), Guidance on the Registration of Project Activities under a Programme of Activities as a Single CDM Project Activity. ACM0014: Treatment of Wastewater Version 6. Available from: https://www.cdm.unfccc.int/methodologies/DB/3WR2RD30NKR6IDVCD4V65VN1XVPWAQ. [Last accessed on 2016 Feb 10].

UNFCCC. (2014b), Guidance on the Registration of Project Activities under a Programme of Activities as a Single CDM Project Activity. AMS-III.G: Landfill Methane Recovery Version 9.0. Sectoral scope(s), 13. Available from: https://www.cdm.unfccc.int/methodologies/DB/QPVDNPHDG8302KQ5EPGD3OC57KVA3Q. [Last accessed on 2016 Feb 10].

UNFCCC. (2015), Guidance on the Registration of Project Activities under a Programme of Activities as a Single CDM Project Activity. AMS-III.H: Methane Recovery in Wastewater Treatment Version 18. Sectoral scope(s), 13. Available from: https://www.cdm.unfccc.int/methodologies/DB/5JGU2EUK716KG3UAE2HBVCK16K199K. [Last accessed on 2016 Feb 10].

Vivanpatarakij, S., Wangjiraniran, W., Nidhiritdhikrai, R., Wiwattanadat, D. (2012), Potential study of electricity generation 1000 MW with biogas in Thailand. Advanced Materials Research, 622-623, 1209-1212.

Weiss, P., Lefèvre, T., Möst, D. (2008), Modelling the impacts of CDM incentives for the Thai electricity sector. Energy Policy, 36(3), 1134-1147.